IEC TS 61400-3-2

Edition 1.0 2019-04

TECHNICAL SPECIFICATION

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

colour inside

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Wind energy generation systems –
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INTERNATIONAL
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FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

Technical Specification IEC TS 61400-3-2 has been prepared by IEC technical committee 88: Wind energy generation systems.

This part is to be read in conjunction with IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements* and IEC 61400-3-1:2019, *Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines*.

From Clause 2 forward, this document does not replicate text from IEC 61400-1 and IEC 61400-3-1; instead, the section headings (including numbering) and text from IEC 61400-3-1 apply to this document except where noted. Exceptions include additions, deletions, or changes in requirements for FOWT relative to fixed offshore wind turbines. New clauses, subclauses, annexes, equations, tables, and terms and definitions in this document are numbered sequentially following the last corresponding number from IEC 61400-3-1.

The text of this technical specification is based on the following documents:

DTS	Report on voting
88/649/DTS	88/673/RVDTS

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

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

A list of all parts of 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 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 an offshore wind turbine 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, which is a technical specification, specifies additional 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 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 is considered as a FOWT if the floating substructure is subject to hydrodynamic loading and supported by buoyancy and a station-keeping system. A FOWT encompasses five principal subsystems: the RNA, the tower, the floating substructure, the station-keeping system and the on-board 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:

a) ship-shaped structures and barges,
b) semi-submersibles (Semi),
c) spar buoys (Spar),
d) tension-leg platforms/buoys (TLP / TLB).

In addition to the structural types listed above, this document generally covers other floating platforms intended to support wind turbines. These other structures can have a great range of variability in geometry 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. Additional considerations might be needed for multi-turbine units on a single floating substructure, vertical-axis wind turbines, or combined wind/wave energy systems.

This document is to be used together with the appropriate IEC and ISO standards mentioned in Clause 2. In particular, this document is intended to be fully consistent with the requirements of IEC 61400-1 and IEC 61400-3-1. The safety level of the FOWT designed according to this document is to be at or exceed the level inherent in IEC 61400-1 and IEC 61400-3-1.

2 Normative references

Replacement of Clause 2 of IEC 61400-3-1:2019.

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

IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements*

IEC 61400-3-1:2019, *Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines*

ISO 19901-1:2015, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating conditions*

ISO 19901-4:2016, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations*

ISO 19901-6:2009, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 6: Marine operations*

ISO 19901-7:2013, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

ISO 19904-1:2006, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semisubmersibles and spars*

ISO 19906:2010, *Petroleum and natural gas industries – Arctic offshore structures*

IMO Resolution MSC.267(85), *International Code on Intact Stability*, 2008 (2008 IS CODE)

API RP 2FPS: 2011, *Recommended Practice for Planning, Designing, and Constructing Floating Production Systems*

API RP 2T (R2015): 2010, *Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply in addition to, or replacing, those stated in IEC 61400-1 and IEC 61400-3-1.

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

3.54
splash zone
external region of the FOWT support structure that is frequently wetted due to waves, tidal variations and floating substructure motions

Note 1 to entry: To define upper and lower limits 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.

Note 2 to entry: While splash zone is not explicitly mentioned in this document, the definition given in this document replaces the definition found in IEC 61400-3-1, which affects the interpretation of IEC 61400-3-1 for FOWT.

3.58
support structure
part of a FOWT consisting of the tower, floating substructure, and stationkeeping system

Note 1 to entry: Refer to Figure 1.

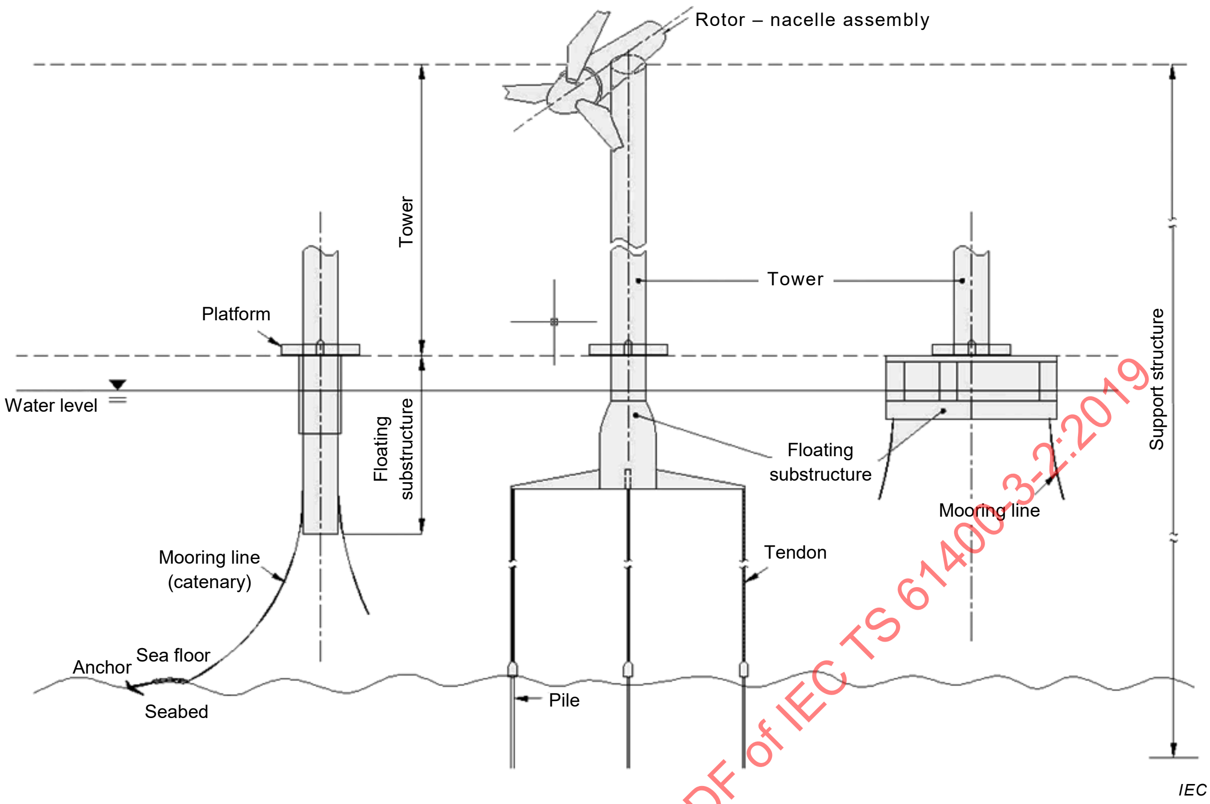
3.79
anchor
device attached to the end of the mooring line or tendon and partially or fully buried in the seabed to limit the movement of the mooring line or tendon and to transfer loads to the seabed

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.

3.80
catenary mooring
mooring system where the restoring action is provided by the distributed weight of mooring lines

3.81
floating substructure
part of a FOWT support structure that floats above the sea floor, connects to the tower and station-keeping 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 an offshore wind turbine.



From left to right: Spar, TLP, and Semi.

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

3.82
mooring system
passive type of station-keeping system that typically comprises mooring lines, anchors, connectors and hardware and may include other components such as buoys, clamped weights, turrets, disconnecting system, etc.

3.83
recognized classification society
member of the International Association of Classification Societies (IACS), with recognized and relevant competence and experience in floating structures

3.84
redundancy check
design situation where a FOWT has reached a new position after one mooring line or tendon has broken and is now held in position by the remaining mooring lines or tendons

3.85
scantling
sizing of plates, girders and stiffeners of floating substructures

3.86
station-keeping 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 station-keeping system may differ from a mooring system in the case of active thrusters, tendons, etc.

3.87
taut-line mooring
mooring system where the restoring action is provided by elastic deformation of mooring lines

3.88
tendon
collection of components of a station-keeping system that forms a vertical link between the TLP-type floating substructure and the foundation on and beneath the sea floor for the purpose of providing station-keeping and floating stability to FOWTs

4 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply in addition to those stated in IEC 61400-1 and IEC 61400-3-1:

4.1 Symbols and units

$f_{\text{low frequency}}$	upper end of low-frequency range	[Hz]
L_k	velocity component integral scale parameter	[m]
$S.F.$	safety factor	[-]
$\sigma_{\text{allowable}}$	allowable stress	[N/mm^2 or MPa]
σ_{buckling}	allowable buckling stress	[N/mm^2 or MPa]
σ_{cr}	critical compressive buckling stress or shear buckling stress	[N/mm^2 or MPa]
σ_{y}	specified minimum yield strength	[N/mm^2 or MPa]

4.2 Abbreviations

For the purposes of this document, the following abbreviated terms apply in addition to those stated in IEC 61400-1 and IEC 61400-3-1:

FOWT	floating offshore wind turbine
IACS	international association of classification societies
IMO	international maritime organization
RCS	recognized classification society
TLB	tension-leg buoy
TLP	tension-leg platform
WSD	working stress design

5 Principal elements

5.2 Design methods

The design methodology summarized in IEC 61400-3-1:2019, Subclause 5.2, is basically able to be applied to FOWT, with the following modifications, illustrated in Figure 2.

The design of the FOWT support structure shall include the design of the station-keeping system per Clause 14 and consider floating stability per Clause 15.

Due to the additional compliance of the station-keeping system of FOWTs relative to fixed offshore wind turbines and the changed dynamic response (including couplings to the RNA), it may be less likely that an RNA initially designed as a standard wind turbine class as defined in IEC 61400-1:2019, Subclause 6.2, is suitable for use in a FOWT.

It is necessary to demonstrate 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 calculated for the specific FOWT support-structure and the specific site conditions with those calculated during the initial RNA design.

The potentially increased dynamic response of FOWT relative to fixed offshore wind turbines also has implications for the design of the control and protection system (see Clause 8), mechanical systems (see Clause 9), and tower.

In lieu of testing described in IEC 61400-3-1, data from model-scale testing may be used to increase confidence in predicted design values and to verify structural-dynamics models and design situations (see Annex K).

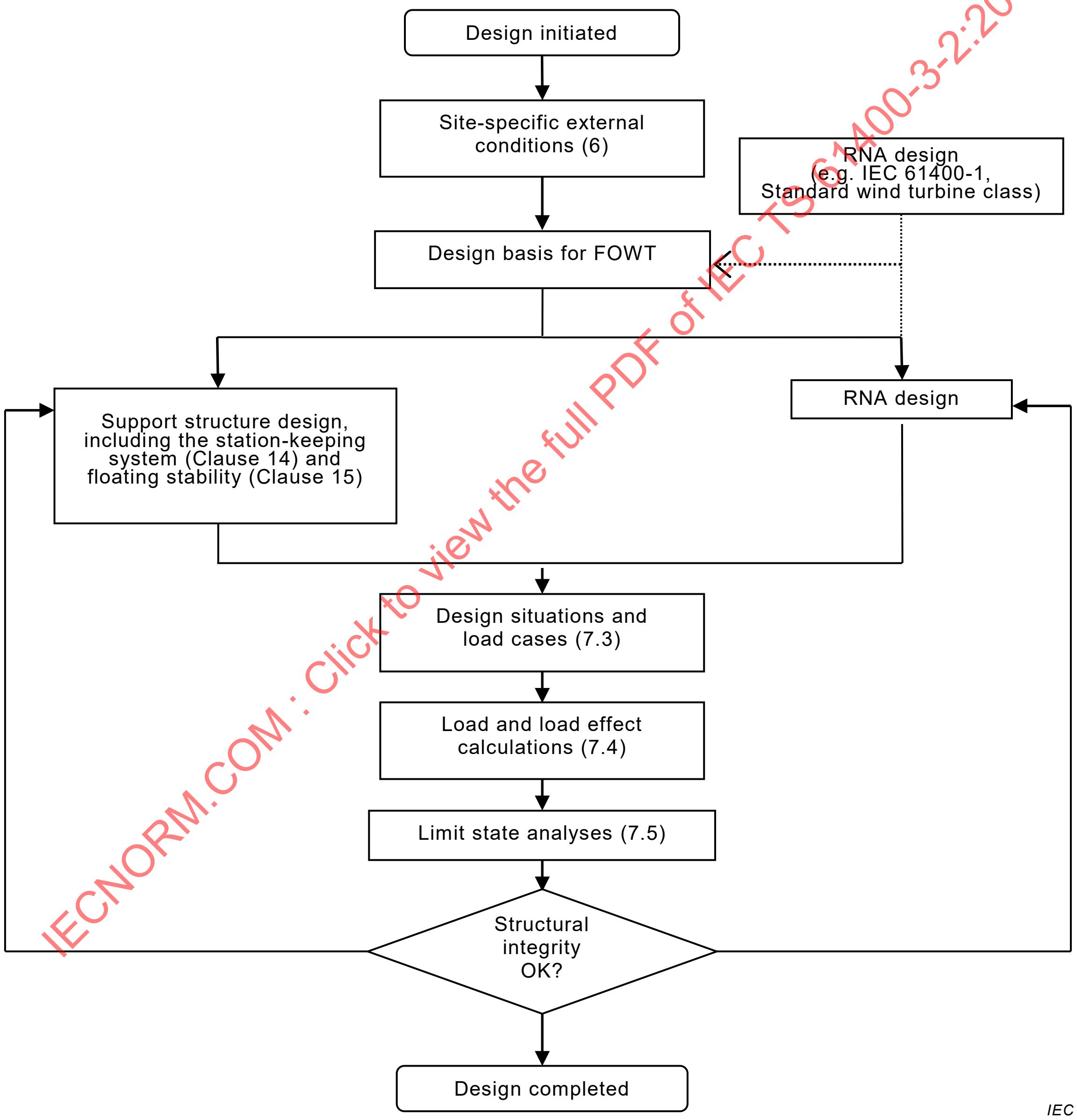


Figure 2 – Design process for a floating offshore wind turbine (FOWT)

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:

- model and serial number;
- production year;
- displacement;
- draft marking (combined load line markings for operating in sea operation);
- company and registered owner identification;
- manufacturer and country;
- owner;

6 External conditions – definition and assessment

6.1 General

6.1.1 In addition to IEC 61400-3-1, the external conditions described in this clause shall be considered in the design of a FOWT. The external conditions defined in IEC 61400-3-1:2019, Clause 6 can basically be applied, but due to the FOWT support structure being a floating system, some additional aspects regarding wind, wave and other external conditions have to be considered.

6.1.2 Wind conditions

It shall be ensured that the representation of the wind in the low-frequency range is adequate. This includes, but is not limited to, an adequate representation of power spectral density in the low-frequency range as well as adequate models for representation of gust events. In particular, this affects the extreme operating gust (EOG) as defined in IEC 61400-1:2019, Subclause 6.3.2.2.

The upper end of the low-frequency range (in Hz) is indicated by the frequency

$$f_{\text{low frequency}} = \frac{V_{\text{hub}}}{6L_{\text{k}}} \tag{23}$$

where V_{hub} is the wind speed (in m/s) at hub height averaged over 10 min and L_{k} is the velocity component integral scale parameter (in m), defined in IEC 61400-1:2019, Annex B. A turbulence model often applicable at low frequencies is described in ISO 19901-1:2015, Clause A.7.4.

Gust event durations for EOG, EDC, ECD defined in IEC 61400-1:2019-–, Subclause 6.3.2, may be inadequate for FOWT design due to possible FOWT motion natural frequencies that are considerably lower than for fixed systems and shall be evaluated, if relevant. For methods to address longer EOG periods (see Annex O).

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.[1]

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

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.

6.3.5 Other environmental conditions

Specific attention should be paid to the assessment of the seismic analysis in the case of TLP/TLB-type floating substructures (see Annex J).

7 Structural design

7.1 General

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

The station-keeping system shall be designed as per Clause 14.

7.3 Loads

7.3.2 Gravitational and inertial loads

IEC 61400-3-1:2019, Subclause 7.3.2 is generally applicable. Inertial loads, including gyroscopic loads, are of special importance to FOWTs due to their potentially additional compliance and increased dynamic response from aerodynamic and hydrodynamic loading.

7.3.3 Aerodynamic loads

IEC 61400-3-1:2019, Subclause 7.3.3 is generally applicable. The aerodynamic interaction between the airflow and the FOWT is of special importance due to their additional compliance and increased dynamic response. The interaction of potentially large translational and rotational motions of the floating substructure with the aerodynamic loading of the RNA and tower shall be considered, including aeroelastic effects and the associated global and local dynamic and unsteady aerodynamic effects (e.g. dynamic inflow, oblique inflow, skewed wake, unsteady airfoil aerodynamics including dynamic stall, blade-vortex interaction). Wind loads on the floating substructure shall also be considered, where relevant.

7.3.5 Hydrodynamic loads

Air gap should have a minimum value of 1,5 m. The air gap shall be determined by appropriate model tests and/or calculated using detailed global performance analyses that account for relative motions between the floating substructure and waves. When assessing the air gap requirement, consideration shall be given to the effect of wave run-up and motions of the floating substructure. The wave run-up is principally affected by the geometry of the structure, wave height, and wave steepness and is typically determined through model tests. Local wave crest elevation shall be taken into account as appropriate, refer to API RP 2FPS. As a minimum, the requirement of air gap shall be checked for the DLCs associated with extreme storms with a return period of 50 years.

Additionally, to IEC 61400-3-1, strength for wave impact load including slamming, sloshing and green water in accordance with ISO 19904-1 shall be assessed.

7.3.6 Sea/lake ice loads

Annex D of IEC 61400-3-1:2019 does not apply to FOWTs. See Annex D.

7.3.7 Other loads

Wake effects from neighbouring FOWTs during power production shall be considered. The assessment of the suitability of a FOWT at a site in an offshore wind farm shall take into account the deterministic and turbulent flow characteristics associated with single or multiple wakes from upwind machines, including the effects of the spacing between the machines, for all ambient wind speeds and wind directions relevant to power production.

The wake behind a wind turbine introduces a wind velocity deficit that tends to meander plus additional turbulence from what is present in the natural free stream. When wakes from one or more upwind machines partially impinge on a downwind rotor, large asymmetric loads (including yaw loads) can be produced on the downwind rotor. These loads and resulting response from dynamic motion may be especially important in FOWTs that are soft in yaw as a result of their station-keeping system configuration. The floating substructure motion shall be accounted for when applying wake models described in IEC 61400-1.

Mooring, tendon and power cable loads have important effects. See Clause 14.

Hydrostatic loads acting on the floating substructure because of internal and external static pressures and resulting buoyancy shall be taken into account where appropriate, including time-varying contribution from hydrostatic pressure due to heave, roll and pitch displacements of the structure from its mean position.

Regarding the effect of earthquake loading for floating structures, see Annex J.

For sites prone to tsunamis, a tsunami shall be generally considered as variance of water surface elevation and horizontal current; see Annex L. If a suitable tsunami warning system is in place to shut down the wind turbine, the tsunami condition can be analysed without considering additional loading from the operating turbine.

7.4 Design situations and load cases

IEC 61400-3-1:2019, Subclause 7.4 shall be applied where applicable to FOWT systems. Additional considerations from particular aspects of FOWT shall be considered.

For each DLC, if wind, wave, swell and current misalignment can lead to higher loading for FOWT, this misalignment shall be considered, including in cases where IEC 61400-3-1:2019, Subclause 7.4 specifies co-directionality.

The extreme operating gust (EOG in DLC 2.3, 3.2 and 4.2) shall be additionally investigated with a longer duration for FOWTs (see Annex O).

In the case of fault conditions (DLC 2.1 to 2.6 and 7.1 to 7.2), for FOWTs with active control systems in the support structure (e.g. active ballast or stationkeeping systems with active thrusters), faults of such systems shall be considered.

In addition to the design load cases defined in IEC 61400-3-1, the specific load cases for FOWT in Table 2 shall be considered.

Table 2 – FOWT specific design load cases

Design Situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
2) Power production plus occurrence of fault	2.6	NTM $V_{in} < V_{hub} < V_{out}$	SSS	MIS, MUL	NCM	NWLR	Fault of sea-state limit protection system	U	A
4) Normal shut down	4.3	NTM $V_{in} < V_{hub} < V_{out}$	SSS or the most severe conditions that triggers the safety limits of the control and protection system	MIS, MUL	NCM	MSL	Maximum operating sea state limit	U	N
9) Power production	9.1	NTM $V_{in} < V_{hub} < V_{out}$	NSS	MIS, MUL	NCM	MSL	Transient condition between intact and redundancy check condition	U	A
	9.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS	MIS, MUL	NCM	MSL	Redundancy check condition	U	A
	9.3	NTM $V_{in} < V_{hub} < V_{out}$	NSS	MIS, MUL	NCM	MSL	Leakage (damage stability)	U	A
10) Parked (standing still or idling)	10.1	EWM $V_{hub} = V_{ref}$	ESS	MIS, MUL	ECM	EWLR	Transient condition between intact and redundancy check condition	U	A
	10.2	EWM $V_{hub} = V_{ref}$	ESS	MIS, MUL	ECM	EWLR	Redundancy check condition	U	A
	10.3	EWM $V_{hub} = V_{ref}$	ESS	MIS, MUL	ECM	EWLR	Leakage (damage stability)	U	A

The designer is allowed to limit the operation of the wind turbine in extreme conditions with specific functions of the control and protection system. The control and protection system functionality shall be described according to the requirements in Clause 8 and the operational limits can be defined by a sea state or by other measure signal. It may be that the control and protection system will not allow operations at the conditions described in DLC 1.6. When this can be proven, DLC 1.6 can be run at the most severe conditions allowable by the control and protection system.

In order to take into account the shut-down transient, DLC 4.3 shall be simulated. DLC 4.3 is defined as the normal shutdown when the control and protection system limits for extreme conditions are exceeded. The potential fault of the control and protection system preventing the turbine to operate at extreme conditions shall be simulated in DLC 2.6. DLC 2.6 is considered as abnormal.

DLC 9.1 and 10.1 correspond to a transient situation between the intact condition (all mooring lines or tendons are intact) and the redundancy condition after the loss of a mooring line or tendon, as defined in 3.84. DLC 9.2 and 10.2 is the situation after one mooring line or tendon breaks and the structure has reached a new mean position.

For FOWT with more than one compartment, the load cases DLC 9.3 and 10.3 shall be investigated for all relevant flooding. The flooding conditions shall be chosen according to damage stability requirements.

The definition of the design load cases DLC 10.1 to DLC 10.3 is the same as for DLC 9.1 to DLC 9.3, with the exception of the wind and sea conditions. In the first group (DLC 9.1 to DLC 9.3), the NTM wind model shall be used in combination with normal sea state (NSS), while in the second group (DLC 10.1 to 10.3) the extreme wind model (EWM) shall be used in combination with extreme sea state (ESS). For the latter it is sufficient to consider $H_{s,50}$ only.

During the simulations of load cases DLCs 9.1 to 10.3, the FOWT may experience a severe movement and yaw misalignment (e.g., yaw movements where in the worst case the incident flow of the rotor can move from upwind to downwind) and shall be considered if relevant.

DLCs 9.1, 9.2, 10.1 and 10.2 can be neglected for the case of non-redundant station-keeping systems, but additional safety factors are required in this case (see Clause 14).

Possible anchor offsets from the design position during the installation of the station-keeping system shall be considered in all DLCs if relevant.

7.5 Load and load effect calculations

7.5.1 General

Frequency-domain methods have historically been used to analyse offshore floating structures, whereas time-domain methods are typically used in wind turbine analysis to account for nonlinearities in the aerodynamics, structural dynamics, and control system. If frequency-domain methods are to be applied in the analysis of FOWT, the calculated loads shall be shown to achieve a level of safety equivalent, or superior, to the level achieved through accepted time-domain methods for each load case where the frequency-domain method is applied.

7.5.2 Relevance of hydrodynamic loads

The hydrodynamic and station-keeping system loads acting on the floating substructure of a FOWT are able to affect the tower and RNA directly as a consequence of dynamic response of the support structure and are in general not negligible and can be important.

7.5.3 Calculation of hydrodynamic loads

IEC 61400-3-1:2019, Subclause 7.5.3 is generally applicable. However, the potentially large volume and large motions of floating substructures used for FOWTs may have an impact on the calculation of hydrodynamic loads relative to fixed offshore wind turbines. Proper treatment of these effects should be considered where appropriate.

Diffraction can be important for large volume structures, whereby the structure significantly modifies the wave pattern. In this case, hydrodynamic loads cannot be calculated using water particle kinematics solved in the absence of the structure. One result of this is that IEC 61400-3-1's recommended constrained wave calculation method cannot be applied, whereby a nonlinear regular wave is embedded into a series of irregular linear waves from which hydrodynamic loads are calculated using Morison's equation. Instead, where diffraction is important, the stochastic and nonlinear nature of waves and hydrodynamic loads can be accounted for using second- (or higher-) order potential-flow wave-body interaction theory, including mean-drift, slow-drift (difference-frequency), and sum-frequency effects where appropriate. Springing and ringing excitation of TLPs/TLBs are of particular importance to the design of the taut-line moorings and tendons.

Wave radiation loading, including memory effects, can be important for large structures undergoing large motion, whereby motion of the structure generates free-surface waves. In this case, the loading is proportional to the oscillatory velocity and acceleration of the structure and depends on its history of motion. The associated loading, including frequency-dependent added mass and damping, can be calculated by potential-flow wave-body interaction theory where appropriate.

Potential-flow wave-body interaction theory is commonly applied assuming that the floating substructure responds as a rigid body. However, the compliance of the floating substructure, including hydro-elastic effects, should be considered where appropriate.

The hydrodynamic loads from potential-flow wave-body interaction theory should be augmented with the loads brought about by flow separation, including viscous drag. Viscous effects are of particular importance to the damping of heave plates.

In case the Morison equation is used to compute the dynamic loads on the platform from waves (generally valid approach for hydrodynamically transparent slender structures, e.g. spars), the vertical forces on tapered parts and on the bottom surface of the structure from the undisturbed wave field (Froude-Krylov force) and possible diffraction forces shall be taken into account.

Annex C provides guidance to enable the calculation of the hydrodynamic loads on the floating substructure.

7.5.4 Calculation of sea/lake ice loads

Annex D of IEC 61400-3-1:2019 does not apply to FOWTs. Instead, sea ice shall be considered according to ISO 19906. In addition, sea ice loads shall be considered in combination with motions of the FOWT due to loads from ice, wind, wave or current processes. The flexibility of the station-keeping system shall be considered when determining sea ice loads.

If sections of the station-keeping system and electrical cable are exposed to sea ice loads, such loading shall be considered.

An ice-management system may be used to reduce loading due to ice action. The effect of ice management on the behaviour of the FOWT shall be taken into account in the design.

7.5.6 Simulation requirements

Following the principles of IEC 61400-3-1:2019–, Subclause 7.5.6, simulation requirements for the specific load cases of FOWT are given below:

- For DLC 2.6, the same requirements specified for DLC 1.6 shall be applied.
- For DLC 4.3, 9.1, 9.2, 9.3, 10.1, 10.2 and 10.3, at least six 10-min simulations shall be carried out for each event at the given wind speed and sea state. Other requirements as specified in this subclause shall also be applied as appropriate.

IEC 61400-3-1:2019, Subclause 7.5.6 is generally applicable to FOWT. However, the unique design features and dynamic properties of FOWTs relative to fixed offshore wind turbines warrant variations of the simulation requirements. The following considerations shall be addressed where appropriate.

In FOWTs there is greater potential for motion of the support structure, which combined with a lack of aerodynamic damping in the side-to-side direction, may cause wind, wave, and current directionality to more heavily impact both ultimate and fatigue loading. The impact of wind and wave/current misalignment is of particular concern to the FOWT support structure and shall be considered for each DLC, including in cases where IEC 61400-3-1:2019, Subclause 7.4 specifies co-directionality.

To ensure statistical reliability of the calculated loads, one ideally would consider all probable combinations of wind speed and wind direction; wave height, wave period, and wave direction; current speed and direction; and tidal variation. Partitioning the probable range of each of these environmental parameters into appropriately sized bins where simulations can be run is key to performing a loads analysis of sufficient accuracy with reasonable computational effort. As a way to reduce the total number of bins required, coarse resolution of the direction and wave-period ranges may be sufficient.

Within each bin, it is important to perform the loads analysis with an appropriate number of adequate-length simulations to ensure the statistical reliability of the calculated structural loads. The appropriate number and length of simulations shall be determined for each DLC based on the FOWT support structure and the site-specific offshore conditions, but should not be less than those specified in IEC 61400-3-1:2019, Subclause 7.5.6. IEC 61400-3-1 recommends 10-minute simulations for most DLCs, with at least 6 random wind and wave seeds, resulting in 60 minutes of stochastic wind and wave inputs for each environmental condition. The 10-minute simulation length is based on the spectral gap of wind variation, which occurs between the turbulent and diurnal peaks in the wind spectrum. Ten minutes of turbulent wind can be approximated as stationary within this frequency band. Similar reasoning in the offshore oil and gas industry has led to common practice of applying 1 hour to 6 hours per simulation for floating systems to account for the spectral gap of waves at a lower frequency, the low natural frequencies of floating substructures, and second-order slow-drift hydrodynamic effects.

Simply running longer wind turbine simulations may not be satisfactory. Turbulent wind simulations often assume a stationary wind condition, so, the turbulent wind generated with simulation times much longer than 1 hour is unphysical. Also, generating turbulent wind data with adequate spatial extent, adequate spatial and time resolution, and simulation times much longer than 1 hour is too computationally expensive for most computers to generate and store. Moreover, increasing the simulation length introduces additional stochastic information (and larger extremes) that itself will result in larger ultimate structural loads, independent of offshore considerations.

To avoid these wind data problems, the use of repeated periodic wind data is recommended if FOWT considerations necessitate running simulations much longer than 10 minutes. Turbulent wind data generated through Fourier-transform techniques are periodic with a period equal to the length of the dataset (typically 10 minutes). This periodic wind data can be successively repeated for simulations involving combined wind and wave excitation longer than 10 minutes using wave data based on the total simulation length (up to 6 hours). But it should be ensured that the use of periodic wind data does not excite low-frequency response of the FOWT.

For extreme sea states, the mean wind speed and significant wave height derived from the site assessment corresponding to a given reference period should be adjusted to the simulation length.

For ultimate loads on FOWTs with negligible slow-drift effects, it is possible that the length of individual simulations need not be longer than 10 minutes as long as the number of simulations is sufficient to ensure the statistical reliability of the calculated structural loads. That is, it is possible that the same ultimate loads can be calculated using simulations of different length, as long as the total amount of random information in the stochastic wind and wave data is kept constant by varying the number of simulations. An assessment of the simulation-length requirements may require one to compare ultimate loads between simulations of different length. To compare ultimate loads between simulations of different length, the averaging technique is important. One should either compare the ultimate load from the same total simulation length, or divide the longer simulations into the length of the shortest simulation and compare the average maxima.

For fatigue loads on FOWTs, it is possible that there is greater sensitivity to the method of counting unclosed cycles compared to the simulation length – see 7.6.3.

Deterministic wind conditions typically lead to extreme loading of system components over short periods of time (on the order of seconds). The phasing between the short periods of extreme loading and the potentially low-frequency but large-amplitude motion of the floating substructure may be important.

In FOWTs the range of support-structure frequencies may be considerably lower than for fixed systems. Therefore, in order to capture potentially extreme loads or enough fatigue cycles during the transients, the simulation length for start-up and shutdown events may need to be increased for FOWTs.

Because the initial conditions used for the dynamic simulations typically have an effect on the response statistics during the beginning of the simulation period, an appropriate amount of initial data shall be eliminated from consideration in any analysis. This initial condition solution is more important for FOWT because FOWT typically have long natural periods of the floating substructure and low damping. The appropriate time shall be chosen such that initial numeric transient effects have sufficiently decayed and the floating substructure has reached a quasi-stationary position. To decrease this initial time in each simulation, it is suggested that the states of the numerical model (especially blade-pitch angle, rotor speed, floating substructure surge, and floating substructure heal) be initialized according to the specific prevalent wind, wave and operational conditions.

7.5.7 Other requirements

In addition to other requirements stated in IEC 61400-3-1:2019–, Subclause 7.5.7, the following shall also be taken into account, where relevant:

- the behaviour of the control and protection system of the wind turbine and floating substructure;
- vortex-induced vibrations and motions of the floating substructure and station-keeping system (refer to Annex C);
- influence of nonlinearities and dynamics, including damping, in catenary, semi-taut or taut station-keeping systems (refer to ISO 19901-7, or for tendons, API RP 2T);
- nonlinear interaction of mooring lines and anchors with seabed;
- dynamic excitation (whipping) and vibration (springing) of the floating substructure from slam impulses (refer to Annex C);
- sloshing.

7.6 Ultimate limit state analysis

7.6.1 General

IEC 61400-3-1:2019, Subclause 7.6 is generally applicable to FOWT with the additions / replacements given in this clause. Because additional requirements relevant to the design of floating substructures shall follow ISO 19904-1 that applies a different limit state analysis method, Annex N provides clarification on these differences and how the differences can be resolved.

Structural assessment of floating substructures for the limit states in association with the DLCs shall be performed using a suitable method to verify the adequacy of the scantling (definition per ISO 19904-1) determined in accordance with scantling equations in RCS rules.

Structural design of the FOWT support structure shall be based on either the partial factor design format per IEC 61400-3-1:2019, Subclause 7.6, or the working stress design (WSD) format – see Subclause 7.6.6. As per ISO 19904-1, the partial factor design format and the WSD format are treated as parallel requirements. For the fatigue design of the FOWT support structure in accordance with ISO 19904-1, all partial safety factors are set to unity, so the partial safety factor format is equivalent to the WSD format.

Additionally, a serviceability analysis shall also be performed as part of the ultimate limit state analysis of a FOWT – see Subclause 7.6.7.

7.6.3 Fatigue failure

Unclosed cycles play an important role in fatigue analysis of FOWT, particularly for shorter simulations. Unclosed cycles, also called half or partial cycles, are generated by rainflow-counting algorithms when peaks cannot be matched with equivalent but opposite amplitude valleys. Unclosed cycles are created at the beginning and end of time-domain simulations, and for large amplitude cycles. A weighting factor between zero and one is applied to these unclosed cycles when the final damage is calculated. If a weighting factor of one is used, each unclosed cycle is treated as if it was a full cycle, and if zero is used, the unclosed cycles are disregarded, having no effect on the fatigue calculation. A factor of 0,5 is commonly recommended as a compromise. It is possible that there is greater sensitivity in the fatigue loads to the method of counting unclosed cycles compared to the simulation length. To minimize this sensitivity, the fatigue-counting algorithm should be processed with all of the simulations from each bin concatenated into one dataset instead of processed separately.

7.6.6 Working stress design method

For a design check of the FOWT support structure in accordance with the WSD format, all partial factors as referenced in Table 4 are equal to unity and design values are taken as the representative values; appropriate global safety factors or utilization factors are applied in design checks.

When the strength design is based on the WSD methods, the design acceptance criteria are expressed in terms of appropriate allowable stress. In the WSD, a single safety factor, $S.F.$, based on design condition and the kind of stress, is used together with the specified minimum yield strength, σ_{y}, to determine the allowable stress, $\sigma_{\mathrm{allowable}}$, by equation (23).

$$\sigma_{\mathrm{allowable}} = \frac{\sigma_{\mathrm{y}}}{S.F.} \tag{24}$$

For beam columns and tubular members, the individual stress components shall not exceed the allowable stress. For plated structures under multiaxial loading conditions, the stress should be formulated in terms of the von Mises stress (or equivalent) and shall not exceed the allowable stress.

In general, the safety factor for yielding shall be according to Table 4. Lower safety factors for yield stress may be used where the magnitudes of loads have been established by measurement or by analysis confirmed by measurement to a higher than normal degree of confidence. The values of all safety factors for yield stress used shall be stated in the design documentation.

Table 4 – Safety factor for yield stress

Kind of stress	Normal (N)	Abnormal (A)	Transport and erection (T)
Axial	1,5	1,25	1,67
Bending	1,5	1,25	1,67
Shear	2,26	1,89	2,52
Von Mises	1,33	1,11	1,48

In addition to the above, the stress in a structural member, due to compression, bending or shear shall not exceed the following allowable buckling stress σ_{buckling}, determined by the critical compressive buckling stress or shear buckling stress σ_{cr} divided by a safety factor $S.F.$ in equation (24).

$$\sigma_{\text{buckling}} = \frac{\sigma_{\text{cr}}}{S.F.} \tag{25}$$

In general, safety factor for buckling shall be taken as 1,50 for normal (N), 1,25 for abnormal (A) and 1,67 for transport and erection (T). However, if the magnitudes of loads have been established by measurement or by analysis confirmed by measurement to a higher than normal degree of confidence, the safety factor shall be taken as 1,25 for normal (N), 1,04 for abnormal (A) and 1,39 for transport and erection (T).

Additional requirements for allowable stresses of beam columns and tubular joints subjected to compression, bending or their combinations should be in accordance with recognized offshore standards.

7.6.7 Serviceability analysis

The design of the FOWT shall satisfy requirements for safe operation during its envisaged operating life. Excess of limiting values regarding FOWT motions that may cause damage to subsea cabling or neighbouring facilities, deformations of the rotor blades, inclination of the tower, etc., which may not necessarily have negative impact within the load simulations, can in reality prevent the FOWT from safe operation and therefore have to be avoided. The designer shall propose appropriate limiting values to ensure the integrity and serviceability of the FOWT and related infrastructure and it shall be verified that these limiting values are not exceeded in all design load cases considered in 7.4. In the serviceability analysis, the partial load factors and partial resistance factors shall be taken as unity in the partial factor design method; the safety factors shall be taken as unity in the WSD method.

8 Control system

In addition to the requirements stated in IEC 61400-1 and IEC 61400-3-1, the control and protection systems of the FOWT support structure (e.g., a ballast control system) shall meet applicable recognized offshore design standards.

Due to the possible additional systems required for the FOWT support structure, interactions between multiple control and protection systems should be considered in the design.

Resonance and dynamic amplification of motions due to control system actions shall be properly mitigated.[2]

In addition to the protection system functions defined in IEC 61400-1:2019, Clause 8, the protection system shall be activated at least in the following dangerous events:

- failure of the control function of the FOWT support structure,
- motions and accelerations of the floating substructure exceed operational limits,
- tower inclination angle exceeds operational limits.

9 Mechanical systems

Some FOWTs will exhibit greater motion than land-based and fixed offshore wind turbines. The inclination angle of the floating substructure due to pitch and roll motion is of particular importance. The designer shall ensure that this dynamic motion and mean static inclination is taken into account in the design, wear, and lubrication of the mechanical systems, including systems pertaining to the RNA as described in IEC 61400-1 and IEC 61400-3-1, and systems and equipment unique to floating support structures.

10 Electrical systems

Electrical systems of the FOWT support structure shall be in accordance with IEC or RCS rules.

11 Foundation and substructure design

Clause 11 of IEC 61400-3-1:2019 does not apply to FOWTs.

Requirements related to anchor design and site, soil and rock characterization for the anchor locations of station-keeping systems are given in ISO 19901-4 and ISO 19901-7. Annex E identifies sources of further specific guidance relating to the design of anchor foundations for FOWTs.

12 Assembly, installation and erection

12.1 General

See ISO 19901-6 for applicable items that are not addressed by IEC 61400-3-1:–, Clause 12.

12.2 General

Particular consideration should be given to transportation operations and intermediate assembly steps.

Stability and structural integrity of the FOWT during assembly, transportation and installation operations should be verified in the design stage against the most adverse environmental conditions defined in IEC 61400-3-1:2019, Subclause 12.5.

[2] A consequence of conventional blade-pitch control of wind turbines is that mean rotor thrust is reduced with increasing wind speed above rated. If applicable, the designer shall consider this condition and ensure that any negative damping of the FOWT system is properly mitigated in the fore-aft direction – including motions from tower bending and platform surge and pitch – across all normal operating conditions.

Regarding towing conditions, the towed object, including cargo and securing arrangements, should be designed to withstand the loads caused by the most adverse environmental conditions defined in IEC 61400-3-1:2019, Subclause 12.5.

12.3 Planning

In addition to IEC 61400-3-1, the planning shall include procedures for the installation of stationkeeping systems, electrical cables and floating substructure.

12.13 Floating specific items

See ISO 19901-6 for floating unique items such as wet tow, ballasting, mooring hook-up, etc.

13 Commissioning, operation and maintenance

13.1 General

For more floating-specific guidance regarding commissioning, operation and maintenance, see ISO 19901-6.

13.3 Instructions concerning commissioning

The commissioning of the onboard machinery, equipment and systems such as ballast systems, pumps, compressors, generators, electrical and control systems, firefighting equipment, etc. that are not part of the RNA shall include both functionality and capacity trials in accordance with approved procedures. For those onboard machinery, equipment and systems that have no redundancy, the commissioning tests prior to operation shall be sufficient to prove reliability for in-service conditions.

13.4 Operator's instruction manual

13.4.1 General

Additional requirements that apply to marine operations of FOWT support structures are specified in ISO 19904-1 as part of the marine operations manual.

13.4.6 Emergency procedures plan

In preparing the emergency procedures plan, for FOWTs, it shall also be taken into account that the risk for structural damage may be increased by situations such as the following:

- mooring line or tendon breaking event,
- failure of FOWT support structure control functions.

13.5 Maintenance manual

Additionally, with regards to IEC 61400-3-1, the description of the subsystems of the FOWT and their operation should also be covered in the manual.

14 Stationkeeping systems

The design of a catenary, semi-taut or taut station-keeping systems shall be basically in accordance with ISO 19901-7; for tendons, refer to API RP 2T. Design situations and load cases shall be defined in accordance with 7.4. In the case of non-redundant station-keeping systems, an increase in safety factors is to be considered to reach the same level of safety as for a redundant station-keeping system (see Annex M). Simulations for the loads analysis of the FOWTs (see Clause 7) shall account for the interactions among the RNA, tower, floating substructure, station-keeping system, and if deemed necessary, power cables.

Additional deviations from ISO 19901-7 are:

- Return period for environmental condition shall be a minimum of 50 years.
- If mooring line capacity is increased due to other factors than minimum required break-strength, the design of chain stopper, fairleads and their foundation (i.e., structural reinforcement) in the floating substructure should be based on maximum tension experienced by the mooring line together with appropriate safety factors rather than the strength of the mooring line.

Tendon systems, including tendon bodies, connectors and foundation not covered by ISO 19901-7, shall be in general designed in accordance with API RP 2T. The following additional considerations shall be applied:

- The return period of environmental conditions for the robustness check may be defined to attain at least the same level of safety as the FOWT.
- For the tendon system using tendon bodies not comprising tubular steel, the design criteria for tendon bodies and connectors shall be determined such as the tendon system can achieve at least the same safety class of the FOWT.

15 Floating stability

15.1 General

The floating behaviour shall be consistent with the requirements for stability in all conditions including intact and damaged configurations, for both temporary and in-service conditions.

15.2 Intact static stability criteria

The stability (righting stability) requirements are to follow the applicable parts of IMO intact stability code, Resolution MSC.267(85) or other recognized standards. Quasi-static effects of various turbine RNA operation conditions (overturning moment equivalent to the one produced by any operational and extreme design load conditions, which are represented by the DLCs – see Clause 7) are to be considered for the stability analysis.

In addition, stability criteria requirements from the local authorities shall be met, unless exemptions from local authority requirements are granted by the local authorities.

15.3 Alternative intact stability criteria based on dynamic-response

As an alternative, the dynamic-response-based intact stability criteria provides a rational safety margin against capsizing and downflooding by incorporating the dynamic motion response characteristics derived from the DLCs (see Clause 7) into the stability criteria.

Guidance for developing alternative intact stability criteria based on dynamic responses can be found in the IMO Intact stability code, Resolution MSC.267(85).

15.4 Damage stability criteria

For unmanned FOWTs in the damaged condition, damage stability may not be required if both of the following conditions are still satisfied:

- Human safety is not compromised, there is no unreasonable threat of harm to the marine environment and collisions with other FOWTs in the FOWT farm and other neighbouring facilities are avoided and.
- The joint probability of loss of stability and subsequent total loss of the structure does not exceed the probability of failure corresponding to the safety level used for assessing the structural integrity of the structure.

In the consideration of damage stability, DLC 9.3 and DLC 10.3 in Table 2 shall be applied as the design situations and load cases.

The damage stability considerations for which the joint probability of total loss of the structure is assessed should address any single watertight compartment listed below located wholly or partially below the final waterline associated with any mode of operation afloat and assumed independently flooded, regardless of exposure and source of the assumed flooding:

- a compartment containing pumps used for the handling of water ballast, or
- a compartment containing machinery with a sea water cooling system, or
- a compartment adjacent to the sea.

16 Materials

Material requirements for station-keeping systems and floating substructures should follow ISO 19901-7 and ISO 19904-1, as applicable.

The structural arrangement shall be adequately protected against corrosion. The method of protection shall be suitable for its intended position and purpose. Guidance regarding corrosion protection systems and how these are accounted for in the design can be found in ISO 19904-1.

17 Marine support systems

17.1 General

Marine support systems of FOWTs should in general be designed in accordance with ISO 19901-4 or other recognized standards along with the following considerations in this clause.

17.2 Bilge system

Except for permanently flooded tanks, means of pumping from or draining all tanks and void compartments shall be provided. If portable power pumps are used in lieu of a permanent bilge system, a minimum of two such pumps shall be provided and either stored onboard the FOWT or carried by the attending service vessel. The pumps and arrangements for pumping shall be made readily accessible.

17.3 Ballast system

The ballast system shall provide the capability to ballast and deballast all ballast tanks that are not used as permanent ballast tanks. All pumps and valves shall be fitted with a remote means of operation. The normal or emergency operation of the ballast system shall not introduce a greater risk of progressive flooding due to the opening of hatches, manholes, etc. in watertight boundaries. Reference is made to the IMO Intact stability code, Resolution MSC.267(85) for further guidance, as appropriate.

Potential freezing of the ballast water shall be considered in the design, if relevant.

Annex A
(informative)

Key design parameters for a floating offshore wind turbine

Replacement of Annex A of IEC 61400-3-1:2019.

A.1 Floating offshore wind turbine identifiers

A.1.1 General

For a floating offshore wind turbine, the following information should be given in a summary included in the design documentation:

- name and type of wind turbine (description),
- location coordinates.

A.1.2 Rotor nacelle assembly (machine) parameters

The following parameters should be given:

- rated power [kW]
- rotor diameter [m]
- rotational speed range [rpm]
- power regulation (stall/pitch)
- hub height (above MSL) [m]
- hub height operating wind speed range $V_{in} - V_{out}$ [m/s]
- design life time [y]
- operational weight (minimum, maximum) [kg]
- corrosion protection of rotor nacelle assembly (description)
- maximum inclination during operation [deg]
- maximum inclination during standby [deg]
- maximum acceleration during operation [m/s/s]
- maximum acceleration during standby [m/s/s]

A.1.3 Support structure parameters

The following parameters should be given:

- description of floating substructure, including dimensions and maximum draft
- description of station-keeping system
- description of electrical cable
- design water depth [m]
- bathymetry in the vicinity of the wind turbine [m]
- soil conditions at turbine location (description, see IEC 61400-3-1:2019, Subclause 6.4.7)
- resonant frequencies of the support structure (minimum, maximum):
  - at normal operating conditions [Hz]

– at extreme operating conditions [Hz]

- amplitude of floating substructure surge, sway, heave, roll, pitch and yaw response amplitude operators, excluding wind loading
- corrosion allowance [mm]
- corrosion protection (description)
- height of access platform (above MSL) [m]
- description of active ballast or bilge systems

A.1.4 Wind conditions (based on a 10-min reference period and including wind farm wake effects where relevant)

The following information should be given:

- turbulence intensity as a function of mean wind speed used for the NTM and ETM
- annual average wind speed (at hub height) [m/s]
- average inclined flow [º]
- wind speed distribution (Weibull, Rayleigh, measured, other)
- normal wind shear model and parameters
- turbulence model and parameters
- hub height extreme wind speeds V_{e1} and V_{e50} [m/s]
- extreme gust model and parameters for 1- and 50-year return periods
- extreme gust model and parameters for assessing floating platform response
- extreme direction change model and parameters for 1- and 50-year return periods
- extreme coherent gust model and parameters
- extreme coherent gust with direction change model and parameters
- extreme wind shear model and parameters
- wind direction distribution (wind rose)

A.1.5 Marine conditions (based on a 3-hour reference period where relevant)

The following information should be given:

- tidal variation and/or storm surge (50-year return period) [m]
- highest astronomical tide (HAT) [m]
- lowest astronomical tide (LAT) [m]
- highest still water level (HSWL) [m]
- lowest still water level (LSWL) [m]
- significant wave height for 1- and 50-year return periods [m]
- range of peak periods for 1- and 50-year return periods [s]
- individual extreme wave height for 1- and 50-year return periods [m]
- range of associated wave periods for 1- and 50-year return periods [s]
- extreme crest height with a return period of 50 years [m]
- extreme sea surface current for 1- and 50-year return periods [m/s]
- wind and wave joint distribution (H_s,T_p,V) including directionality

- wave spectrum and parameters
- wave spreading distribution and parameters
- deterministic wave model and parameters
- breaking wave model and parameters
- sea ice conditions (description, see 7.3.6)
- local and global scour or sum of both (maximum allowed) [m]
- sea floor level variation (maximum allowed) [m]
- marine growth profile and thickness [mm]

A.1.6 Electrical network conditions at turbine

The following information should be given:

- normal supply voltage and range [V]
- normal supply frequency and range [Hz]
- voltage imbalance [V]
- maximum duration of electrical power network outages [days]
- annual number of electrical network outages [1/year]
- total lifetime duration of network outages [h]
- auto-reclosing cycles (description)
- behaviour during symmetric and unsymmetrical external faults (description)

A.2 Other environmental conditions

The following information should be given:

- normal and extreme air temperature ranges [°C]
- normal and extreme sea temperature ranges [°C]
- air density [kg/m^3]
- water density [kg/m^3]
- solar radiation [W/m^2]
- humidity [%]
- rain, hail, snow and icing
- chemically active substances
- mechanically active particles
- description of lightning protection system
- earthquake model and parameters (description)
- tsunami model and parameters (description)
- salinity [g/m^3]
- duration and environmental conditions assumed for DLC 6.4
- duration and environmental conditions assumed for DLC 7.2
- duration and environmental conditions assumed for DLC 8.3

A.3 Limiting conditions for transport, installation and maintenance

The following information should be given:

- maximum wind speed [m/s]
- maximum significant wave height [m]
- maximum water level variation [m]
- permitted atmospheric temperature [°C]
- maximum wind speed for maintenance [m/s]
- displacement of transport vessel [metric tons]
- maximum and minimum ballast conditions during transport and installation

Annex B
(informative)

Shallow water hydrodynamics and breaking waves

Specific guidance relating to wave kinematics for FOWTs may be found in ISO 19901-1.

Annex C
(informative)

Guidance on calculation of hydrodynamic loads

Specific guidance relating to the calculation of hydrodynamic loads for FOWTs, including hydrostatics, radiation, diffraction, and viscous effects, may be found in ISO 19904-1 and the following RCS rules:

ABS *Guide for Building and Classing Floating Offshore Wind Turbine Installations*

BV, NI572, *Classification and Certification of Floating Offshore Wind Turbine*

DNV, DNV-OS-J103, *Design of Floating Wind Turbine Structures*

Nippon Kaiji Kyokai (ClassNK), *Guidelines for Offshore Floating Wind Turbine Structures*

Annex D
(informative)

Recommendations for design of floating offshore wind turbine support structures with respect to ice loads

Annex D of IEC 61400-3-1:2019 does not apply to FOWTs. For detailed information on ice loading of floating support structures, refer to ISO 19906.

Annex E
(informative)

Floating offshore wind turbine foundation and substructure design

Annex E of IEC 61400-3-1:2019 does not apply to FOWTs.

Specific guidance relating to the design of anchor foundations for FOWTs may be found in the following RCS rules:

ABS *Guide for Building and Classing Floating Offshore Wind Turbine Installations*

DNV, DNV-OS-J103, *Design of floating wind turbine structures*

Annex F
(informative)

Statistical extrapolation of operational metocean parameters for ultimate strength analysis

Annex F of IEC 61400-3-1:2019 applies to FOWTs unchanged.

Annex G
(informative)

Corrosion protection

Guidance regarding corrosion protection systems for FOWTs and how these are accounted for in the design can be found in ISO 19904-1 and ISO 12944-9.

Annex H
(informative)

Prediction of extreme wave heights during tropical cyclones

Annex H of IEC 61400-3-1:2019 applies to FOWTs unchanged.

Annex I
(informative)

Recommendations for alignment of safety levels in tropical cyclone regions

Annex I of IEC 61400-3-1:2019 applies to FOWTs unchanged.

Annex J
(informative)

Earthquakes

Actions resulting from seismic activity shall be considered in the structure design for regions that are considered to be seismically active (see also ISO 19900). However, actions arising from earthquakes are not normally of concern for the design of floating structures (see also ISO 19904-1 and ISO 19901-2).

For the catenary mooring system, earthquakes do not affect floating substructures because of small stiffness, but earthquakes can cause dynamic mooring line tension loading. In case of tendon or taut-line station-keeping systems, the large stiffness causes the inertial force to be transferred to the floating substructure. The dynamic tension generated by the earthquake causes heave motions (and potentially surge and sway motions for taut-line station-keeping systems). For floating substructures with more than one taut line or tendon, it is important to consider the phase of forcing at separate anchor points that can induce rolling and pitching motions. Design of station-keeping systems should be performed according to the relevant ISO standards as described in Clause 14.

The geotechnical conditions for the anchoring system should be checked to determine dynamic soil properties and liquefaction potential (see also ISO 19901-4:2016, Subclause 6.3.2 and Subclause 6.4.2).

Annex K
(informative)

Model tests

The purpose of model tests includes the following two cases:

- the validation of a numerical simulation, including calibration (tuning) of simulation parameters,
- the acquisition of design values, such as a design load.

In the case of parked or idling conditions where the influence of the turbine is negligible, the testing methodology of a conventional offshore structure can basically be applied. In the case of power generating conditions, it is important to use a suitable model for a wind turbine in addition to the testing methodology of the conventional offshore structure. This is possible through combined wind/wave tank testing where a wave tank has been suitably augmented with wind generation equipment or by mimicking the wind loads by other means.

When augmenting a wave tank with wind generation equipment, care should be taken in the design of the wind generation equipment to reduce swirl and minimize unintended wind-generated waves. It should be the normal procedure in combined wind/wave tank testing to apply the appropriately scaled wind load instead of the wind speed. The wind load should be correct in all directions relative to the model. The wind generation equipment should be capable of producing a steady wind load, as well as appropriate wind turbulence.

While a Froude-based scaling approach is, in general, a sound methodology, the approach shall be modified in regard to the rotor due to the aerodynamic loading being so dependent on Reynolds number. If it is not possible to use the same scaling methodology for turbine and floating substructure, it is important to verify that the ratio between aerodynamic and hydrodynamic forces is not too far from the real scale system. It is suggested that coupled wind/wave turbine testing under a Froude-scaled environment should use a blade geometry which is specifically designed for a low Reynolds number environment. This may be accomplished by increasing the blade chord and using airfoils appropriate for low Reynolds number flow, which is often done in wind tunnel tests. While the blade geometry will likely not represent the full-scale architecture in this case, the blade should be designed to match full-scale power and thrust coefficient curves, which will ensure that the global mean forces on the structure are maintained in a Froude-scaled environment. The numerical simulation should use the same Reynolds number as the model-scale test. In case aero-elastic behaviour is critical for the investigated FOWT (e.g. instabilities identified in simulations due to coupling effects), appropriate aero-elastic scaling may be required as well, e.g. Lock-number scaling combined with Froude or Reynolds scaling.

It is possible to mimic wind loads in a wave tank by means other than through wind generation equipment e.g. through a controlled fan used in place of the rotor or through an actuator that can prescribe precomputed or real-time (hardware-in-the-loop, HIL) computed wind loads. With these approaches it is also important to verify that the ratio between aerodynamic and hydrodynamic forces is not too far from the real scale system.

It is recommended that the influence of the blade-pitch control be tested if necessary.

It is necessary to take the following into consideration regarding the relation between the frequency (f_{in}) of external forcing and the natural frequency (f_n) of structural vibration.

i) $f_{in} << f_n$

Structure can be assumed to be a rigid body.[3]

ii) $f_{in} \fallingdotseq f_n$

Because there is possibility of resonance, it is necessary to treat structure flexibility correctly.

iii) $f_{in} >> f_n$

Structure is called flexible structure, and because the influence of elasticity on the whole structural response can be significant, it is necessary to treat structure flexibility correctly.

Model tests with the stationkeeping system are recommended.

Instrumentation, including sensors and their cabling, should be light-weight so as not to alter the dynamic behaviour of the model. It is suggested that wireless sensors be used where possible to avoid the sensor cable from influencing the dynamic response of the model. Care should be taken to avoid producing additional compliance in the tower if load sensors are used to measure tower loads.

It is suggested that model testing of FOWTs be undertaken in accordance with ISO 19904-1:2006, Subclauses 8.12 and 13.2.1 and ISO 19901-7:2013, Subclause 14.6. Further information can be found in ITTC:2017.

It would be advantageous to validate the model-scale wind turbine behaviour independent of the FOWT support structure. While this can be achieved by fixing the floating platform in the tank, it would be best to first perform testing of the wind turbine in a wind tunnel. Tests in wind tunnels equipped with 6-DOF actuators to prescribe pre-calculated or real-time (HIL) computed platform motions may be beneficial to analyze the rotor aerodynamics and validate the control system.

3 Generally floating structures (excluding a tower) can be assumed to be rigid in this domain. But in cases where the size of the floating structure is relatively large, this assumption may not be appropriate.