Guide for Building and Classing

Floating Offshore Wind Turbines

ABS

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GUIDE FOR BUILDING AND CLASSING

FLOATING OFFSHORE WIND TURBINES
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Foreword *(1 July 2020)*

This Guide provides criteria for the design, construction, installation and survey of permanently sited Floating Offshore Wind Turbines. It addresses three principal areas: the floating substructure, the stationkeeping system, and onboard machinery, equipment and systems including applicable marine systems and associated equipment and machinery, safety systems and associated equipment, and lifesaving appliances and machinery.

The criteria applicable to bottom-founded offshore wind turbine substructures and foundations are provided in the ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbines (BOWT Guide)*.

Requirements for ancillary offshore wind farm installations such as meteorological measuring towers, accommodation units, and transformer platforms are not addressed in this Guide. For the requirements for bottom-founded ancillary offshore wind farm installations, refer to the ABS *Rules for Building and Classing Offshore Installations.* The requirements applicable to floating ancillary offshore wind farm installations are provided in the ABS *Rules for Building and Classing Mobile Offshore Units* and the ABS *Rules for Building and Classing Floating Production Installations*.

This revision incorporates the following changes:

- "Installations" or "Installation" as in context "Floating Offshore Wind Turbine Installations" or "Floating Offshore Wind Turbine Installation" deleted.
- 1-1/7.1 – Additional requirements for optional class notation "**RNA**" for the Rotor-Nacelle Assembly (RNA) and the tower added.
- 1-1/7.3 – A new mandatory class notation for "Strength Criteria for Site-specific Conditions (**S**)" added.
- 1-1/7.5 – New mandatory class notations for "Design Fatigue Life" added.
- 1-1/7.7 – New Subsection added to offer applicable notations listed in the ABS *MOU Rules* and the ABS *FPI Rules* upon agreement from ABS.
- 1-1/11.5 – Required design plans for the concrete floating substructure added.
- 1-1/15 – Information for wind turbine control systems and power cable system in information memorandum added.
- 1-1/19.1 – Abbreviation for "NPD" added.
- 1-1/19.2 – References for new revisions of ABS *Guides* and *Rules*, API and IEC standards, and ACI and ASTM standards for concrete structures added.
- 3-1/23 – A new Subsection for "Consideration for Identical Floating Substructure Design" added.
- 4-2/3 and 4-2/11.1– Requirements are aligned with API RP 2MET for storm wind models.
- 4-2/11 – Requirements aligned with IEC 61400-3-2 for extreme wind models.
- 4-3/1 – Requirements aligned with the IEC 61400-3-2 for consideration of swell conditions.
- 5-2/3 – Design Load Cases (DLCs) modified to incorporate the recent updates in the IEC 61400-3-1 and IEC TS 61400-3-2.
- 5-2/Table 1 – New design load cases (new DLC 2.5, DLC 2.6, DLC 9.1, 9.2, 9.3, DLC 10.1, 10.2 and DLC 10.3) added to incorporate the recent updates in the IEC 61400-3-1 and IEC TS 61400-3-2.
- 5-2/3.5 – A load case added where the tendon is designed to be subject to planned replacement.
- 6-1/7 – Additional design load cases DLC 10.1, DLC 10.2 and DLC 10.3 added for air gap analysis.
- 6-1/7 – Reference made to the ABS *Guidance Notes on Air Gap and Wave Impact Analysis for Semi-Submersibles*.

- Section 7-3 – Detailed requirements added for concrete floating substructure.
- 7-2/7.5 – The LRFD design referred to the ABS *Guide for Load and Resistance Factor Design (LRFD) Criteria for Offshore Structures*.
- 8-1/9 – New Subsection added to provide guidance on "Redundant Mooring System".
- 8-5/11 – Added new Subsection is to provide guidance on "Dynamically Embedded Plate Anchor".
- Section 8-6 – Reference is made to ABS *FPI Rules* for "Field Test".
- 9-2/5.1.1 – DLC 4.1 and DLC 4.3 for normal shutdown, and DLC 5.1 for emergency stop added as design load cases to be considered in intact stability calculation.
- 9-2/5.3 – DLC 9.3 for power production and DLC 10.3 for parked condition added as required design load cases for damage stability calculation.
- 10-1/1 – Title of the Subsection changed to "General" to introduce the design requirements in Chapter 10 for machinery, equipment and systems.
- 10-1/11 – New Subsection on "Identification Marks" for Floating Offshore Wind Turbines added.
- 11-1/1 – Added survey requirements to denote when the turbine and tower are within the scope of classification.
- 11-1/5.1 – Modified requirements for installation and hook-up surveys for the RNA, tower, and power cable system.
- 11-2/1 – Added survey requirements to denote when the turbine and tower are within the scope of classification.
- 11-2/3 – A new Subsection and requirements for "In-Service Inspection Program (ISIP)" added. Referred Section for risk-based inspection in the Guide added.
- 11-2/5.5 – A new Subsection "Underwater Inspection in Lieu of Drydocking Survey (UWILD)" added.
- 11-2/17 – A new Subsection "Inspection for Concrete Structures" added.
- 11-2/19 – This Subsection replaced with new title and content in "Preparations for Safe Execution of Surveys".
- Appendix A1 – A new Appendix added to provide guidance on wind spectra and coherence functions.
- Appendix A2 – A new Appendix added to provide guidance on tropical cyclone wind speed profile, standard deviation, turbulence intensity and gust factor.
- Various other changes are made to clarify the requirements.

This Guide becomes effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of this Guide is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org .

GUIDE FOR BUILDING AND CLASSING

FLOATING OFFSHORE WIND TURBINES

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CHAPTER 1
Conditions of Classification

SECTION 1
Scope and Conditions of Classification

1 Classification *(1 July 2020)*

The general requirements for conditions of classification are contained in the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

Additional requirements specific to the Floating Offshore Wind Turbine are contained in the following Subsections.

3 Classification Boundaries *(1 July 2020)*

The classification of the Floating Offshore Wind Turbine addresses three principal areas which are subject to the requirements of this Guide:

i) The floating substructure, which carries the wind turbine Rotor-Nacelle Assembly (RNA) and tower.

ii) The stationkeeping system; and

iii) Applicable marine systems and associated equipment and machinery, safety systems and associated equipment, and lifesaving appliances and machinery

Additionally, at the request of the Owner, the RNA and the tower as defined in 1-1/17.3.26 and 1-1/17.3.34 may be included in the classification. Optional notations for the RNA and the tower will be added to ABS *Record* subject to the satisfactory compliance with the requirements given in 1-1/7.1.

Where the RNA and tower are not included in the classification, the RNA and tower installed on the ABS classed Floating Offshore Wind Turbine are required to have a type certificate in accordance with IECRE OD-501 or other recognized standards. The type certificate will be reviewed by ABS solely to confirm it is current and verify that the information of the installed RNA and tower are consistent with the design information, criteria and limitations considered in the classification of the Floating Offshore Wind Turbine. ABS will not review or be responsible for the accuracy of the type certificate.

Where the tower and its connection to the RNA are not covered by the wind turbine type certificate and the optional class notation is not requested, the tower and its connection to the RNA are to be included in the scope of classification.

Where interface structures of the tower connecting to the substructure are not covered by the wind turbine type certificate and the optional class notation is not requested, these interface structures are to be included in the scope of classification.

RNAs lacking a type certification or the wind turbines possessing a non-horizontal-axis configuration are subject to special consideration by ABS. Design documents are to be submitted for review. Scope of the design review is to be defined on a case-by-case basis.

In this Guide, the Floating Offshore Wind Turbine is considered as an unmanned structure.

5 Offshore Wind Turbines Built under ABS Survey *(1 July 2020)*

The following class notations apply to the Floating Offshore Wind Turbine, as defined in 1-1/3 and further in 1-1/17.3.8.

5.1 Offshore Wind Turbines Built under ABS Survey *(1 July 2020)*

Offshore wind turbines built and constructed to the satisfaction of the ABS Surveyors and to the requirements of this Guide or to their equivalent, where approved by ABS, may be classed and distinguished in the ABS *Record* by the following symbol:

✠ A1 Offshore Wind Turbine (Floating)

The mark ✠ (Maltese cross) signifies that the offshore wind turbine was built, installed and commissioned to the satisfaction of the ABS Surveyors.

5.3 Offshore Wind Turbines Not Built under ABS Survey *(1 July 2020)*

Offshore wind turbines not built under ABS survey but submitted for classification are subject to special classification survey. Where found satisfactory and thereafter approved by ABS, such offshore wind turbines may be classed with the symbol:

A1 Offshore Wind Turbine (Floating)

7 Additional Class Notation *(1 July 2020)*

7.1 Notation for Rotor-Nacelle Assembly (RNA) and Tower *(1 July 2020)*

The RNA and tower may be considered for the classification at the Owner's request. A Floating Offshore Wind Turbine may be classed and distinguished in the *Record* by the optional class notation **RNA** if:

i) The RNA and tower are in compliance with the ABS Type Approval requirements in the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*, and

ii) The site-specific assessment demonstrates, as a minimum, that loads and deflections calculated for the Floating Offshore Wind Turbine under the site-specific conditions do not exceed those calculated for the RNA and tower approved by the ABS Type Approval.

7.3 Strength Criteria for Site-specific Conditions (S) *(1 July 2020)*

For the Floating Offshore Wind Turbine designed and built to the requirements for pre-service conditions and strength criteria for in-service site-specific conditions in accordance with this Guide and maintained in accordance with the applicable ABS requirements, the site-specific environmental data and electric network condition data for in-service conditions will be indicated by the **(S)** qualifier following the basic notation of 1-1/5.1 and 1-1/5.3 as described in the following Subparagraphs.

The **(S)** qualifier followed by the definition of the site is mandatory to be assigned and published in the ABS *Record*.

7.3.1 New Construction

This qualifier **(S)** will be followed by the definition of the site. For example:

✠ A1 Offshore Wind Turbine (Floating) (S) Gulf of Maine

A1 Offshore Wind Turbine (Floating) (S) Gulf of Maine

7.3.2 Life Extension of Floating Offshore Wind Turbines at the Same Site *(1 July 2020)*

For life extension of a Floating Offshore Wind Turbine remaining at the same site, the intended period of operation is extended. The strength of the Floating Offshore Wind Turbine is to be reassessed to demonstrate that it remains in compliance with applicable requirements.

If the environmental criteria for the site or operating area have been revised since the original approval due to new environmental data or changing environmental conditions, the coastal State may require the use of new environmental criteria for the life extension.

For the life extension of a Floating Offshore Wind Turbine remaining at the same site, the following actions are to be taken:

- Structural strength analysis and fatigue life re-evaluation reports, as required in 1-1/7.5.2.
- Design review and surveys related to any major modifications affecting class items.
- Special survey, including Underwater Inspection, to determine the structural condition of the Floating Offshore Wind Turbine at the time of the life extension.

Survey requirements for extension of use are given in 11-2/23.

After the life extension is completed in accordance with this Guide, the qualifier **(S)** notation can be retained for the site.

7.3.3 Relocation of Floating Offshore Wind Turbines

A Floating Offshore Wind Turbine is designed and classed for a specific site location where it will be operated for an intended period. When the Floating Offshore Wind Turbine is relocated to a new site, either within the same offshore wind farm or in a different operating area, the strength of the Floating Offshore Wind Turbine is to be reassessed to confirm that it remains in compliance with applicable requirements.

7.3.3(a) Relocation within the Same Offshore Wind Farm

If the environmental conditions for the offshore wind farm have been revised since the original approval due to new environmental data or changing environmental conditions, the coastal State may require the use of new environmental conditions for the relocation, in which case the same requirements as those required for relocation to a different operating area will apply.

It is expected that relocation within the same offshore wind farm will require at least a new stationkeeping system for the new site. When the original stationkeeping system or part of the components are to be re-used, the condition of the stationkeeping system or the components is to be be assessed. The design assessment is to be performed. For the relocation within the same offshore wind farm, without exceeding the original design life of the Floating Offshore Wind Turbine, the following actions are to be taken:

- Design review and surveys related to the new stationkeeping system.
- Design review and surveys related to any other modifications affecting class items.
- Survey reports, including gauging to bring the Floating Offshore Wind Turbine to a satisfactory condition to complete the remaining design life at the specific site.

The expected operating life in the new location may be within the original design life or otherwise it may extend beyond the original design life. In the latter case, in addition to the requirements for relocation, the requirements for life extension will apply. The design and assessment reports as required in 1-1/7.3.2 are to be submitted for review.

Survey requirements for relocation are given in 11-2/25.

After the relocation is completed in accordance with this Guide, the qualifier **(S)** notation can be updated for the new site.

7.3.3(b) Relocation to a Different Operating Area

For a Floating Offshore Wind Turbine to be relocated to an operating area where the site conditions are different than those at the original site, the structural strength and fatigue life of the Floating Offshore Wind Turbine are to be reassessed for the new conditions. However, if the new location has milder environmental conditions than the current site and comparable electrical network conditions, the reassessment may not be necessary, provided that the Floating Offshore Wind Turbine maintains the same structural condition as at the original site and the design fatigue life of the Floating Offshore Wind Turbine is not extended.

Relocation to a different operating area will require a new stationkeeping system for the new site and the following actions:

- Structural strength analysis and fatigue life re-evaluation reports, as required in 1-1/7.5.3.
- Design review and surveys related to the new stationkeeping system
- Design review and surveys related to any other modifications affecting class items.
- Survey reports, including gauging to bring the Floating Offshore Wind Turbine to a satisfactory condition to complete the remaining design life at the specific site.

The expected operating life in the new location may be within the original design life or otherwise it may extend beyond the original design life. In the latter case, in addition to the requirements for relocation, the requirements for life extension will apply. The design and assessment reports as listed in 1-1/7.3.2 are to be submitted for review.

Survey requirements for relocation are given in 11-2/25.

After the relocation is completed in accordance with this Guide, the qualifier **(S)** notation can be updated for the new site.

7.5 Design Fatigue Life *(1 July 2020)*

7.5.1 New Construction

The design fatigue life value notation is to be assigned and published in the *Record*. The "design fatigue life" refers to the target value set by the owner or designer, not the value calculated in the analysis. The design fatigue life is to be verified to be in compliance with the fatigue criteria in this Guide. The class notation **FL(number of years), Year** will be assigned to identify the design fatigue life in years and the year of maturation of fatigue life in the defined site. For example, **FL(25), 2045** for a Floating Offshore Wind Turbine built in 2020 if the minimum design fatigue life specified is 25 years.

Where the design fatigue life for the floating substructure differs from that of the stationkeeping system, the notation **FL(number of years), Year** will be followed by the notation **FLM(number of years), Year**, where **(number of years)** refers to the design fatigue life for the stationkeeping system and **Year** refers to the year of maturation associated with the stationkeeping system.

The class notation **FL(number of years), Year** and/or **FLM(number of years), Year** is mandatory to be assigned and published in the ABS *Record*.

7.5.2 Life Extension of Floating Offshore Wind Turbines at the Same Site

When the operating life of a Floating Offshore Wind Turbine exceeds the design fatigue life specified in either **FL(number of years), Year,** or in **FLM(number of years), Year** notation for which it was classed, an evaluation is to be made and appropriate actions are to be taken to extend the use of the Floating Offshore Wind Turbine up to the new operating life under the site-specific conditions.

For the life extension of the Floating Offshore Wind Turbine remaining in the same location, the following actions are to be taken:

- Verification from the original fatigue analysis that the actual fatigue values of all the structural elements of the Floating Offshore Wind Turbine are still higher than the proposed extended fatigue life; or
- New fatigue analysis covering all the structural elements in accordance with **FL** or **FLM** requirements, as applicable.
- Identification of structural elements or details with a fatigue life below the new intended design fatigue life of the Floating Offshore Wind Turbine and proposed actions to increase the fatigue life of those elements or details.
- Design review and surveys of structural modifications proposed as a consequence of the fatigue analysis.
- Enhanced survey program to monitor those structural elements or details with lower fatigue life which cannot be modified or renewed on site.
- Special survey, including Underwater Inspection, to determine the structural condition of the Floating Offshore Wind Turbine at the time of the life extension.

Survey requirements for extension of use are given in 11-2/23.

After the life extension is completed in accordance with this Guide, the existing **FL** or **FLM** notation with total number of fatigue life and year of maturation is to be updated accordingly.

7.5.3 Relocation of Floating Offshore Wind Turbines

When a Floating Offshore Wind Turbine is relocated to a new site, either within the same offshore wind farm or in a different operating area, the fatigue life of the Floating Offshore Wind Turbine is to be reassessed to demonstrate that the remaining fatigue life for the new operating conditions is within the design fatigue life of the Floating Offshore Wind Turbine.

Survey requirements for relocation are given in 11-2/25.

After the relocation is completed in accordance with this Guide, the existing **FL** or **FLM** notation can be retained for the new site.

7.6 Other Class Notations *(1 July 2020)*

When requested by the Owner, applicable notations listed in the ABS *MOU Rules* and ABS *FPI Rules* may be assigned upon agreement from ABS.

9 Rules for Classification

9.1 Application *(1 July 2020)*

The requirements of this Guide are applicable to Floating Offshore Wind Turbines as defined in 1-1/3 and further in 1-1/17.3.8.

This Guide is applicable to those features that are permanent in nature and can be verified by plan review, calculation, physical survey or other appropriate means. Any statement in this document regarding other features is to be considered as guidance to the designer, Fabricator, Owner, et al.

9.3 References *(1 July 2020)*

References are made in this Guide to ABS Rules and other criteria issued by ABS and other organizations. 1-1/19 contains a list of such references. Unless otherwise noted, the applicable edition of a reference is the one officially issued and available on the date the Agreement for Classification is accepted by ABS. Where a particular edition or date associated with a reference is given, it means that particular edition is relevant to the topic being presented in this Guide. ABS may consider at its discretion, upon the request of the Owner, the application of other appropriate alternative methods and recognized codes of practice.

9.5 Alternatives *(1 July 2020)*

Any departure from the requirements of this Guide may be considered by ABS on the basis of suitable engineering analyses or risk assessments. In the case of such departures, classification is subject to ABS's approval upon a demonstration of acceptable levels of safety in line with the principles of this Guide (see 3-1/3) and recognized and generally accepted current offshore wind industry practice. Risk acceptance criteria are subject to approval by ABS. See the ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Industries* for an overview of risk assessment techniques and additional information.

Using a risk assessment approach to justify alternatives may be applicable either to the Floating Offshore Wind Turbine as a whole or to individual systems, subsystems or components. As appropriate, remote hazards outside of the bounds of the system under consideration are to be taken into account. Such account must include incidents relating to remote hazards directly affecting or being influenced by the system under consideration. ABS will consider the application of risk-based techniques in the design of the Floating Offshore Wind Turbine as well as surveys during construction and surveys for maintenance of class.

Portions of the Floating Offshore Wind Turbine not included in the risk assessment are to comply with the applicable parts of the ABS Rules.

The following are the responsibility of the Owner:

i) Risk acceptance criteria

ii) Hazard identification

iii) Risk assessment

iv) Risk management

v) Compliance with the applicable requirements of the coastal State or other governmental authorities

11 Design Documentation to be Submitted *(1 July 2020)*

The design documentation to be submitted is to describe the data, tools, procedures and methodologies of design and analysis which are employed to establish the design of the Floating Offshore Wind Turbine. The intended design life is also to be stated. It is recommended that a list of drawings which are planned for ABS approval is to be developed and submitted for review prior to detailed plans are submitted.

Where model testing is used as a basis for a design, the applicability of test results depends on the demonstration of the adequacy of the methods employed, including enumeration of possible sources of error, limits of applicability, and methods of extrapolation to full scale. Preferably, procedures are to be reviewed and agreed upon before model testing is done.

As required in the subsequent Paragraphs of this Subsection, calculations are to be submitted to demonstrate the sufficiency of a proposed design. Such calculations are to be presented in a logical and well-referenced fashion employing a consistent system of units. Where the calculations are in the form of computer analysis, the submittal is to provide input and output data with computer generated plots for the analysis model. A program description (not code listings), user manuals, and the results of program verification sample problems may be required to be submitted.

The design documentation to be submitted is to include the reports, calculations, plans, specifications and other documentation where applicable. The extensiveness of the submitted documentation is to reflect

i) The uniqueness of a specific design of the Floating Offshore Wind Turbine within an offshore wind farm

ii) The level of experience with conditions in the area where the Floating Offshore Wind Turbine is to be located

iii) Plans or requests related to statutory conventions or exemptions requested by the Flag State or coastal State, where applicable. Owner is to develop a statutory ABS deliverable matrix for review and concurrence in projects early stages.

Design documentation should generally be submitted electronically to ABS. However, hard copies will also be accepted.

11.1 Reports

Reports by consultants and other specialists used as a basis for design are to be submitted for review. The contents of reports on offshore wind farm conditions, environmental considerations, foundation data, and materials are, in general, to comply with the recommended list of items given below.

11.1.1 Offshore Wind Farm Conditions *(1 July 2020)*

A report on offshore wind farm conditions is to present the configuration of an offshore wind farm and the exact locations of all individual floating offshore wind turbines, subsea cables, transformer platform, service and accommodation units and any other supporting structures and facilities in the offshore wind farm where applicable.

The report is also to contain information on wind turbines, particularly those properties that are used as the input or as the basis of the input for the design of the Floating Offshore Wind Turbine.

11.1.2 Environmental Considerations *(1 July 2020)*

Reports on environmental considerations, as described in Section 4-1, are to describe all environmental phenomena appropriate to the areas for the pre-service (load-out, transportation, installation and commissioning) and in-service (operation, maintenance and repair) phases. The types of environmental phenomena to be accounted for, as appropriate to the type and location of the Floating Offshore Wind Turbine, include wind, waves, currents, temperature, tide, marine growth, chemical components and density of air and water, snow and ice, earthquake and other pertinent phenomena.

The establishment of environmental conditions is to be based on appropriate original data or, when permitted, data from analogous areas. Demonstrably valid statistical models are to be employed to perform the extrapolation to long-term values. Any calculations required to establish the pertinent environmental conditions are to be submitted for review.

The report on environmental considerations is also to contain the calculations which quantify the effects or loadings on the Floating Offshore Wind Turbine where these are not provided in other documentation.

11.1.3 Soil Data *(1 July 2020)*

Reports on soil data are to present the findings of investigations or, where applicable, data from analogous areas on geophysical, geological and geotechnical considerations existing at and near the installation site of anchoring structures of the stationkeeping system. As appropriate to the planned anchoring structure, the manner in which such data is established and the specific items to be assessed are in general to comply with 5-4/1 and 5-4/5 of the ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbines (BOWT Guide)*. The report is to contain a listing of references to cover the investigation, sampling, testing, and interpretive techniques employed during and after the site investigation.

Where applicable, the report is to include a description of the predicted interaction between the soil and the intended anchoring structure of the stationkeeping system. As appropriate to the planned anchoring structure, the items which may need to be covered in the reports are: axial and lateral pile capacities and response characteristics, the effects of cyclic loading on soil strength, scour, settlements and lateral displacements, dynamic interaction between soil and structure, the capacity of pile groups, slope stability, bearing and lateral stability, soil reactions on the structure, and penetration resistance.

Recommendations relative to any special anticipated problem regarding installation are to be included in the report on soil data. Items such as the following are to be included, as appropriate: hammer sizes, soil erosion during installation, bottom preparation, and procedures to be followed in the case that pile anchor installation procedures significantly deviate from those anticipated.

11.1.4 Materials and Welding *(1 July 2020)*

Reports on structural materials and welding may be required for structures or welding procedures where materials or welding procedures do not conform to those provided in Chapter 2 of this Guide.

For metallic structures intending to employ new alloys not defined by a recognized specification, reports are to be submitted indicating the adequacy of the material's metallurgical properties, fracture toughness, yield and tensile strengths, and corrosion resistance, with respect to their intended application and service temperatures.

For a concrete structure, where it is not intended to test or define material properties in accordance with Chapter 2, a report is to be provided indicating the standards to be employed and their relative adequacy with respect to the corresponding standards referenced in Chapter 2.

11.1.5 Model Test

If model testing is performed (for example as per 6-1/9 for the assessment of global performance, Section 5-3 for the determination of environmental loads, or Section 9-2 for establishing the dynamic-response-based intact stability criteria), a model test report containing the information required in the relevant Sections is to be submitted.

11.3 Design Data and Calculations *(1 July 2020)*

Design and analysis calculations are to be submitted for items relating to loadings and responses for operations during the pre-service and in-service phases. Calculations are in general to comply with the items listed below.

Calculations to be provided in association with environmental considerations and soil data are described in 1-1/11.1.

11.3.1 Loadings

Calculations for loadings are to be submitted in accordance with 3-1/9 and Chapter 5.

11.3.2 Stability

Stability analyses are to be performed and the results are to be submitted in accordance with Section 9-2.

11.3.3 Dynamic Properties *(1 July 2020)*

Calculations of natural periods of the Floating Offshore Wind Turbine are to be submitted for review. A resonance diagram (Campbell diagram) depicting the relationship between the rotor speeds and the natural periods of turbine components and the Floating Offshore Wind Turbine is to be submitted.

As applicable, the calculation of vibration amplitudes, velocities and accelerations of the Floating Support Structure may also be required.

11.3.4 Global Performance

Global performance analyses are to be carried out in accordance with 3-1/11 and Chapter 6. Descriptions of analysis methods and calculation results of the parameters listed in 6-1/1 are to be submitted for review.

The design documentation forthe mooring lines and anchors (or tendons and foundation) and other stationkeeping system components is to be submitted in accordance with Chapter 8.

11.3.5 Structural Responses *(1 July 2020)*

Calculations to verify structural adequacy of the floating substructure and the tower (if classed), are to be submitted for review. The appropriate extent and types of analyses and the sophistication of such analyses are dependent on one or a combination of the following factors:

i) The design basis of the structure relative to the conditions to be encountered at the site

ii) The relative lack of experience with the structure's arrangement, local details, loading patterns, and failure mode sensitivities

iii) Potential deleterious interactions with other subsystems of the Floating Offshore Wind Turbine

The required structural analyses are to employ the loads associated with the design load conditions determined in accordance with Chapter 5. More specific information on required structural analyses is given in Chapter 7 for the Floating Support Structure.

11.3.6 Other Calculations *(1 July 2020)*

For the Floating Offshore Wind Turbine carrying the optional **RNA** notation, a site-specific assessment is to be performed to calculate the loads and deflections of the type approved RNA and tower under site-specific conditions.

Calculations are to include those performed in the design of the corrosion protection system. Additional calculations which demonstrate the adequacy of an overall design may also be required.

11.5 Design Plans of Floating Support Structure *(1 July 2020)*

- Plans showing the scantlings, arrangements and details of the principal parts of the floating substructure to be built under survey are to be submitted and approved before the work of construction is commenced. These plans are to clearly indicate the scantlings, joint details and welding, or other methods of connection. In general, plans to be submitted are to include the following, where applicable:

- General arrangement
- Body plan, lines, offsets, curves of form, inboard and outboard profile
- Layout plans indicating the locations, dimension and weights of turbine components (e.g., blade, hub, nacelle, etc.) and the components (e.g., electrical, mechanical and control systems, etc.) in nacelle housing
- Layout plans of secondary structures, fenders, ladders, access platform, boat landing, power cable support, etc.
- Wind heeling moment curves or equivalent data for the Floating Support Structure carrying the RNA
- Thrust curve of the turbine rotor
- Arrangement plan of watertight compartmentation
- Diagrams showing the extent to which the watertight and weathertight integrity are intended to be maintained, as well as the location, type and disposition of watertight and weathertight closures
- Capacity plan and tank sounding tables
- Summary of distributions of weights (fixed, variable, ballast, etc.) for various conditions
- Estimations for additional accumulated masses due to sea sediment resting on structures prone to hold such masses i.e. water entrapment plates
- Type, location and quantities of permanent ballast, if any
- Loadings for all decks
- Tower scantlings and tower-RNA connection details, where applicable
- Tower-hull connection details
- Tower pedestal and foundation (hull structure supporting the tower) details
- Hull transverse section showing scantlings
- Hull longitudinal sections showing scantlings
- Decks, including helicopter deck if applicable
- Framing, shell plating, watertight bulkheads and flats, structural bulkheads and flats, tank bulkheads and flats with location of overflows and air pipes
- Pillars, girders, diagonals and struts
- Stability columns, intermediate columns, hulls, pontoons, superstructure and deck houses
- Arrangement and details of watertight doors and hatches
- Foundations for anchoring equipment, industrial equipment, etc., where attached to hull structure, superstructures or deckhouses
- Mooring turrets and yoke arms, including mechanical details, if applicable
- Corrosion control arrangements
- Specification of floating substructure internal and external coatings / antifoulings
- Structure strength analysis and corrosion consideration due to additional sea sediment mass trapped on structures prone to hold such masses i.e. water entrapment plates
- Welding details and procedures
- Methods and locations for nondestructive testing
- Standard details of hull fabrication
- Information in support of novel features utilized in the design, where applicable

- Documentation to facilitate the survey of concrete quality, as applicable to the Quality Control Program (QCP) (see 11-1/3.9.1 for details), is to be submitted for approval.
- For concrete structures, plans indicating general notes about materials and workmanship, arrangements and details of reinforcement, typical details of concrete cover, the location and detail of construction joints, waterstops, etc.

11.7 Design Documentation of Stationkeeping System *(1 July 2020)*

The design documentation for the stationkeeping system is to include the following, where applicable:

- Mooring arrangement or pattern
- Details of winching equipment
- Details of anchoring system
- Details of mooring line or tendon segments
- Connections at anchors and between mooring line segments
- Details of in-line (spring) buoys
- Details of buoy of catenary anchor leg mooring (CALM) system
- Details of single anchor leg mooring (SALM) structures
- Details of turret system to show turret structure, swivel, and turntable
- Details of yoke (hard or soft) connecting the floating substructure and the CALM/SALM structure
- Reports on wind farm conditions, environmental considerations and soil data, as required in 1-1/11.1
- Global performance analysis report, as required in 1-1/11.3.4
- Model test report where the design loads are based on model tests in a wave basin (see 1-1/11.1.5)

11.9 Design Plans of Machinery and Systems *(1 July 2020)*

Design plans of the onboard machinery and systems addressed in Chapter 10 are to be submitted for review and approval by ABS.

11.9.1 Design Documentation of Electrical Installations

The design documentation for the electrical installation is to include the following, where applicable:

- Electrical one-line diagrams
- Short-circuit current calculations
- Coordination study
- Specifications and data sheets for generators and motors
- Specifications and data sheets for distribution transformers
- Details of storage batteries
- Details of emergency power source
- Standard details of wiring cable and conduit installation practices
- Switchboards and distribution panel
- Panel board

11.9.2 Design Documentation of Instrumentation and Control Systems

The design documentation for the instrumentation and control system is to include the following, where applicable:

- General arrangements
- Data sheet
- Schematic drawings – electrical systems
- Schematic drawings – hydraulic and pneumatic systems
- Programmable electronic systems

11.9.3 Fire Protection and Personnel Safety Design Plans *(1 July 2020)*

The applicability of the following requirements to the submission of design documentation may vary, depending upon the nature of a specific design of the Floating Offshore Wind Turbine.

- Portable or semi-portable extinguishers
- Fire detection and alarm systems
- Fire cause and effect chart
- Heating, ventilation and air conditioning (HVAC) plan [including air handling unit (AHU)], location, duct layout, duct construction and bulkhead and deck penetration details
- Guard rails
- Escape routes (may be included on the fire control plan or separate plan)
- Lifesaving appliances and equipment plan (escape routes must be indicated)

11.9.4 Design Plans for Other Machinery and Systems *(1 July 2020)*

Submission of design plans for other machinery and systems which are described in Chapter 10 but not specified in 1-1/11.9.1 through 1-1/11.9.3 of this Guide is to follow 1-1-7/3 of the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*, where applicable.

11.11 Additional Plans *(1 July 2020)*

Where additional class notations or certification under the other Rules, Guides or regulations, as described in Section 1-1-5 of the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*, are requested, submission of additional plans and calculations may be called for by ABS.

13 Manuals and Procedures

13.1 Operating Manual *(1 July 2020)*

The Operating Manual pertaining to the safe operation of the Floating Offshore Wind Turbine is to be prepared and submitted for review. The Operating Manual is to be retained by the owner or operator and made readily available to the ABS Surveyor and service personnel prior to conducting any maintenance or inspection.

Insofar as classification is concerned, the Operating Manual is to include, as appropriate, the following information:

i) A general description of the Floating Offshore Wind Turbine, including major dimensions, lightship characteristics

ii) A general description and the maintenance record of the RNA and the tower

iii) Summaries of approved modes of operation (See Section 5-2), including for each mode of operation:

- Design environmental conditions, including wave height and period, wind speed, current velocity, minimum air and sea temperatures, air gap, and water depth
- Turbine RNA operating mode in conjunction with the condition of turbine control, protection and electrical systems and the status of electrical network connection
- Design deck loadings, mooring loads, icing loads, variable load, cranes and, if applicable, types of helicopter for which the helideck is designed
- Draft or draft range, disposition of movable equipment such as crane booms, etc.
- Maximum allowable KG versus draft curve or equivalent and associated limitations or assumptions upon which the allowable KG is based (See 9-2/1)
- Disposition (open or closed) of watertight and weathertight closures (See 9-3/1)
- Maximum allowable offset and heeling angle of the Floating Support Structure

iv) Information showing:

- General arrangements
- Type, location and quantities of permanent ballast
- Allowable deck loadings
- Information related to stability and watertight/weathertight integrity, as required in 9-2/5.3, 9-2/7, and 9-3/1
- Capacity, centers of gravity and free surface correction for each tank
- Capacity and centers of gravity of each void provided with sounding arrangements but not provided with means of draining
- Location and means of draining voids
- Hydrostatic curves or equivalent
- Simplified electrical one line diagrams of main power and emergency power systems
- Schematic diagrams of the bilge, ballast and ballast control system

v) Ballasting and deballasting procedure

The Operating Manual is to be reviewed by ABS to verify the operational procedures and conditions are consistent with the design information, criteria and limitations considered in the Floating Offshore Wind Turbine's classification. ABS is not responsible for the operation of floating offshore wind turbines.

The Operating Manual outlined in this subsection does not need to be in addition to that required by the coastal State or other governmental authorities. However, these administrations may require that additional information be included in the Operating Manual.

13.3 Procedures *(1 July 2020)*

Procedures are to be submitted for the following:

- Installation Procedures
- Hook-Up Procedures for connecting the stationkeeping system to the floating substructure
- Procedure for closure weathertightness integrity testing i.e. leak, chalk or hose testing
- Startup and Commissioning Procedures
- In-Service Inspection Program (ISIP), as required in 11-2/3
- Underwater Inspection Procedure or, if applicable, Drydocking Survey Procedure

15 Information Memorandum *(1 July 2020)*

An information memorandum is to be prepared and submitted to ABS. ABS will review the contents of the memorandum to establish consistency with other data submitted for the purpose of obtaining classification. ABS will not review the contents of the memorandum for its accuracy or the features described in the memorandum for their adequacy.

An information memorandum is to contain, as appropriate to the Floating Offshore Wind Turbine, the following:

- Specifications of the RNA and tower suitable to be installed for the site
- Valid wind turbine type certificate for the RNA and tower
- Description of the wind turbine control system concept and the control system (structure of the control system, sequences of the start and stop procedures, behavior of the turbine during normal operation and on detection of malfunctions, statement of trigger criteria)
- Description of turbine control system fault modes and frequency and duration of fault events
- Description of the procedure for manual intervention after the activation of any wind turbine protection functions
- Description of the wind turbine braking systems and their behavior (structure of the braking systems, mode of operation, characteristic quantities, time constants)
- Functional description of the wind turbine locking devices
- Description of the wind turbine control software used for load simulation. (interfaces to the load analysis such as program modules for blade pitching as well as identification of critical load cases)
- Description of the process that confirms that the control system (including software) on the wind turbine has the same behavior as modeled in the load simulation
- Computer software interface of the turbine control system linked to the load analysis program, if an independent analysis is requested
- Site plan indicating the general features at the site and the layout of the offshore wind farm
- Environmental and soil design criteria, including the recurrence interval used to assess environmental phenomena
- Plans showing the general arrangement of the Floating Offshore Wind Turbine
- Description of the safety, protective, security and trespass avoidance systems provided
- Description of the modes of operation
- Description of the export or inter-array power cable termination at the floating substructure
- Listing of governmental authorities having cognizance over the installation
- Listing of any novel features
- Brief description of any monitoring proposed for use on the installation
- Description of pre-service load-out, transportation, installation and commissioning procedures
- Description of on-site maintenance and repair procedures for the Floating Offshore Wind Turbine
- Description of disconnecting, transportation and reconnecting procedures for maintenance and repair operations, if applicable
- A plan to control the procurement of equipment
- An inventory of hazardous materials (IHM) plan

17 Terms and Definitions

17.1 Types of Floating Substructure *(1 July 2020)*

17.1.1 TLP-Type Floating Substructure *(1 July 2020)*

A TLP (Tension Leg Platform) -type floating substructure is a vertically moored, buoyant structural system wherein the excess buoyancy of the platform maintains tension in the stationkeeping system.

A TLP-type floating substructure consists of structural components of hull connecting to the tendon system. It may also include a column top frame and topside deck. The hull consists of buoyant pontoons and columns. The tops of the columns may be connected to the tower directly or to a column top frame or a topside deck forming the global strength of the hull. The tendon system consists of a vertical mooring system that forms the link between the hull and the foundation for the purpose of mooring the floating substructure. The foundation system is used to anchor the tendons to the seafloor.

17.1.2 Spar-Type Floating Substructure *(1 July 2020)*

A Spar-type floating substructure is a deep draft, vertical floating structure, usually of cylindrical shape, supporting the tower and a topside structure (if any) and moored to the seafloor.

A Spar-type floating substructure typically consists of an upper hull, mid-section and lower hull. The upper hull serves to provide buoyancy to support the topside and provides spaces for variable ballast. The mid-section connects the upper hull with the lower hull. The mid-section can be a cylindrical column or a truss space frame with heave plates. The heave plates are a series of horizontal decks between each bay of the truss space frame and are designed to limit heave motions by providing added mass and hydrodynamic damping. The lower hull normally consists of a fixed ballast tank and, in the case of a truss Spar, a flotation tank.

17.1.3 Column-Stabilized Floating Substructure *(1 July 2020)*

A column-stabilized floating substructure consists of a topside structure connected to the underwater hull or footings by columns or caissons. The floating substructure depends upon the buoyancy of columns or caissons for flotation and stability. Lower hulls or footings are normally provided at the bottom of the columns for additional buoyancy. The topside structure can be of an enclosed hull type or an open space frame truss construction. The topside structure is interconnected with the stability columns of the hull to form the overall strength of the floating substructure. The tower may be connected directly to the column or caisson or to the topside structure.

17.1.4 Barge-Type Floating Substructure *(1 July 2020)*

A barge-type floating substructure consists of a buoyancy hull formed by ring buoyancy pontoons with a center damping pool. The floating substructure depends upon the buoyancy of the barge for flotation and stability. The tower may be connected to the barge hull through a tower pedestal on the buoyancy pontoon.

17.1.5 Other Types of Floating Substructures *(1 July 2020)*

Configurations of the floating substructure that do not belong to the types described in 1-1/17.1.1 through 1-1/17.1.4.

17.3 Terminology

17.3.1 Material Applications Categories *(1 July 2020)*

The application of structural members in the floating substructure is to be in accordance with the categories listed in this Paragraph.

17.3.1(a) Special Application Structure. Special application structure refers to highly stressed members, located at intersections of main structural elements and other areas of high stress concentration where the occurrence of a fracture could induce a major structural failure.

17.3.1(b) Primary Application Structure. Primary application structure refers to primary load carrying members of a structure where the occurrence of a fracture could induce a major structural failure.

17.3.1(c) Secondary Application Structure. Secondary application structure refers to less critical members due to a combination of lower stress and favorable geometry or where an incidence of fracture is not likely to induce a major structural failure.

17.3.2 Consultant

A consultant is any person who, through education and experience, has established credentials of professionalism and knowledge in the stated field.

17.3.3 Cut-In Wind Speed (V_{in})

The lowest 10-minute mean wind speed at Hub Height at which the wind turbine starts to produce power in the case of steady wind without turbulence

17.3.4 Cut-Out Wind Speed (V_{out})

The highest 10-minute mean wind speed at Hub Height at which the wind turbine is designed or chosen to produce power in the case of steady wind without turbulence

17.3.5 Design Life

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

17.3.6 Emergency Stop *(1 July 2020)*

Rapid shutdown of the wind turbine triggered by manual intervention.

17.3.7 Fabricator

A Fabricator is any person or organization having the responsibility to perform any or all of the following: fabrication, assembly, erection, inspection, testing, load-out, transportation and installation.

17.3.8 Floating Offshore Wind Turbine *(1 July 2020)*

A Floating Offshore Wind Turbine encompasses three principal areas: the floating substructure (see 1-1/17.3.10) for carrying the wind turbine RNA (see 1-1/17.3.26) and the tower (see 1-1/17.3.34), the Stationkeeping System (see1-1/17.3.29) and the onboard machinery, equipment and systems including applicable marine systems and associated equipment and machinery, safety systems and associated equipment, and lifesaving appliances machinery.

17.3.9 Floating Substructure *(1 July 2020)*

A Floating Substructure of an offshore wind turbine is a site-dependent offshore structure supported by buoyancy and maintained on location by the Stationkeeping System. The floating substructure consists of the hull (see 1-1/17.3.14) and topside structures.

17.3.10 Floating Support Structure *(1 July 2020)*

The Floating Support Structure consists of the tower (see 1-1/17.3.34) and the floating substructure (see 1-1/17.3.9).

17.3.11 Foundation System (for Tendons)

Structural, mechanical and geotechnical components which are located on and beneath the sea floor and transfer the loads acting on the Tendons into the seabed

17.3.12 Gust

Brief rise and fall in wind speed lasting less than 1 minute

17.3.13 Hub Height *(1 July 2020)*

Height of the center of the swept area of the wind turbine rotor above the Still Water Level

17.3.14 Hull

Combination of connected buoyant structural components such as columns, pontoons and intermediate structural braces

17.3.15 Idling

Condition of a wind turbine that is rotating slowly and not producing power

17.3.16 Mean Sea Level or Mean Still Water Level (MSL)

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

17.3.17 Mean Wind Speed

Statistical mean value of the instantaneous wind speed over a specified time interval

17.3.18 Normal Shutdown

Wind turbine shutdown operation in which all stages are under the control of the control system

17.3.19 Offshore Wind Farm

A group of offshore wind turbines installed at an offshore site.

17.3.20 Omni-directional (Wind, Waves or Currents)

Acting in all directions

17.3.21 Owner

An owner is any person or organization who owns offshore wind turbines.

17.3.22 Parked

Condition of a wind turbine that is either in a Standstill or an Idling condition, depending on the design of the wind turbine.

17.3.23 Rated Power

Quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device, or equipment. For wind turbines, it is the maximum continuous electrical power output which a wind turbine is designed to achieve under normal operating and external conditions.

17.3.24 Rated Wind Speed (V_r)

Minimum 10-minute mean wind speed at Hub Height at which a wind turbine's Rated Power is achieved in the case of steady wind without turbulence.

17.3.25 Return Period (Recurrence Period)

A return period is the average time duration between occurrences of an event or of a particular value being exceeded. A return period in years is equal to the reciprocal of the annual probability of exceedance of an event or of a particular value of a random parameter such as wind speed, wave height or sea elevation.

17.3.26 Rotor-Nacelle Assembly (RNA)

The Rotor-Nacelle Assembly of a horizontal axis wind turbine, carried by the Floating Support Structure, consists of:

i) The Rotor components, including blades, hub, shaft, and spinner.

ii) The Nacelle, a housing which contains the mainframe, generator frame, drive train components, electrical generator components, wind turbine control and protection components and other elements on top of the tower.

17.3.27 Splash Zone *(1 July 2020)*

Part of a floating substructure containing the areas above and below the Mean Sea Level and regularly subjected to wetting due to wave actions, motions of the floating substructure and, if applicable, tide and draft variations. Areas which are only wetted during major storms are not included.

17.3.28 Standstill

Condition of a wind turbine that is not rotating

17.3.29 Stationkeeping System *(1 July 2020)*

System capable of limiting the excursions of the floating substructure within prescribed limits, maintaining the intended orientation, and helping to limit motions at tower top.

17.3.30 Still Water Level (SWL)

Abstract water level used for the calculation of wave kinematics and wave crest elevation. Still Water Level, which can be either above or below the Mean Sea Level, is calculated by adding the effect of tide and surge to the Mean Sea Level.

17.3.31 Structural Critical Inspection Point (SCIP) *(1 July 2020)*

Structure Critical Inspection Point (SCIP) is a structural point defined in the ISIP (see 11-2/3) plan as a critical inspection area determined by structural assessment using applicable calculations and analysis.

In general, SCIPs are locations with higher stresses and estimated lower fatigue life. These locations are identified from calculation to require monitoring or from the service history of the subject floating substructure or from similar sister floating substructures to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the unit.

17.3.32 Surveyor

A Surveyor is a person employed by ABS whose principal functions are the surveillance during construction and the survey of marine structures and their components for compliance with the ABS Rules or other standards deemed suitable by ABS.

17.3.33 Tendon *(1 July 2020)*

A system of components, which form a link between the floating substructure and the Foundation System for the purpose of restraining motion of the TLP-type floating substructure in response to environmental and other loading within specified limits.

17.3.34 Tower *(1 July 2020)*

Structure component which connects the floating substructure to the Rotor-Nacelle Assembly

17.3.35 Turbulence Intensity

Ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time.

17.3.36 Uni-directional (Wind, Waves or Currents)

Acting in a single directions

17.3.37 Water Depth

Vertical distance between the sea floor and the Still Water Level

17.3.38 Wind Profile (Wind Shear Law)

Mathematical expression for assumed wind speed variation with height above the Still Water Level

17.3.39 Yaw Misalignment

Horizontal deviation of the wind turbine rotor axis from the wind direction

19 Abbreviations and References

19.1 Abbreviations of Organizations *(1 July 2020)*

ABS	American Bureau of Shipping
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NACE	National Association of Corrosion Engineers
NPD	Norwegian Petroleum Directorate

19.3 References *(1 July 2020)*

i) ABS *FPI Rules* – ABS *Rules for Building and Classing Floating Production Installations*

ii) ABS *MOU Rules* – ABS *Rules for Building and Classing Mobile Offshore Units*

iii) ABS *Offshore Installations Rules* – ABS *Rules for Building and Classing Offshore Installations*

iv) ABS *Rules for Materials and Welding – Part 2*

v) ABS *Marine Vessel Rules* – ABS *Rules for Building and Classing Marine Vessels*

vi) ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbine*

vii) ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures*

viii) ABS Guide for the Fatigue Assessment of Offshore Structures

ix) ABS *Guide for Load and Resistance Factor Design (LRFD) Criteria for Offshore Structures.*

x) ABS *Guide for Nondestructive Inspection*

xi) ABS *Guide for Position Mooring Systems*

xii) ABS Guide for *Risk-Based Inspection for Floating Offshore Installations*

xiii) ABS *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques* *xiv)* ABS *Guidance Notes on Air Gap and Wave Impact Analysis for Semi-Submersibles*

xv) ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*

xvi) ABS *Guidance Notes on Design and Installation of Drag Anchor and Plate Anchor*

xvii) ABS *Guidance Notes on Design and Installation of Dynamically Installed Piles*

xviii) ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbines*

xix) ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Industries*

xx) ABS *Guidance Notes on Review and Approval of Novel Concepts*

xxi) ACI 211.1, *Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete*

xxii) ACI 213R, *Guide for Structural Lightweight Aggregate Concrete*

xxiii) ACI 301, *Specifications for Structural Concrete*

xxiv) ACI 318, *Building Code Requirements for Structural Concrete*

xxv) ACI 357R-84 *Guide for the Design and Construction of Fixed Offshore Concrete Structures*

xxvi) ACI 357.2R-88 *State-of-the-Art Report on Barge-Like Concrete Structures*

xxvii) ACI 359, *Code for Concrete Reactor Vessels and Containments*

xxviii) AISC *Manual of Steel Construction*

xxix) API Bulletin 2N, *Interim Planning, Designing and Constructing Fixed Offshore Structures in Ice Environments*

xxx) API RP 2A-LRFD, *Recommended Practice for Planning Designing and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design*

xxxi) API RP 2A-WSD, *Recommended Practice for Planning Designing and Constructing Fixed Offshore Platforms – Working Stress Design*

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

xxxiii) API RP 2MET, *Recommended Practice for Derivation of Metocean Design and Operating Conditions*

xxxiv) API RP 2SK, *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*

xxxv) API RP 2T, *Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*

xxxvi) API SPEC 17E, *Specification for Subsea Umbilicals*

xxxvii) ASTM C31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*

xxxviii) ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

xxxix) ASTM C94, *Standard Specification for Ready-Mixed Concrete*

xl) ASTM C172, *Standard Practice for Sampling Freshly Mixed Concrete*

xli) ASTM C330, *Specification for Lightweight Aggregates for Structural Concrete*

xlii) IEC 61400-1, *Wind Energy Generation Systems – Part 1: Design Requirements*, 4th Edition, 2019

xliii) IEC 61400-3-1, *Wind Energy Generation Systems – Part 3-1: Design Requirements for Fixed Offshore Wind Turbines*, 1st Edition, 2019

xliv) IEC TS 61400-3-2 (Technical Specification), *Wind Energy Generation Systems – Part 3-2: Design Requirements for Floating Offshore Wind Turbines*, 1st Edition, 2019 *xlv)* IEC 61400-24, *Wind Turbines – Part 24: Lightning protection*, 1st Edition, 2010

xlvi) IECRE OD-501 (Operational Document), *IEC System for Certification to Standards relating to Equipment for use in Renewable Energy applications (IECRE System): Type and Component Certification Scheme*, 2nd Edition, 2018

xlvii) ISO 2533, *Standard Atmosphere*

xlviii) ISO 19904-1, *Petroleum and natural gas industries – Floating Offshore Structures, Part 1: Monohulls, Semi-submersibles and Spars*

xlix) ISO 19903, *Petroleum and natural gas industries - Fixed concrete offshore structures*

l) ISO 19906, *Petroleum and natural gas industries - Arctic offshore structures*

li) NACE SP0108, *Standard Practice: Corrosion Control of Offshore Structures by Protective Coatings*

lii) NACE SP0176, *Standard Practice: Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production*

CHAPTER **2**

Materials and Welding

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CHAPTER 2
Materials and Welding

SECTION 1
General

1 Metallic Materials

Properties of metallic materials are to be in accordance with Section 3-1-4 of the *MOU Rules*. Guidance on determining the material application category (see 1-1/17.3.1) of a hull structural component is provided in Part 5B of the *FPI Rules*.

3 Welding

Requirements for welding are to be in accordance with the ABS *Rules for Materials and Welding (Part 2)*. Section 3-2-6 of the *MOU Rules* is to be used to establish weld designs for the steel Floating Support Structure.

5 Concrete *(1 July 2020)*

Properties of the concrete are to comply with 2-1/3 of the ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbines*, which makes further reference to applicable standards of the American Society for Testing and Materials (ASTM) and the American Concrete Institute (ACI).

7 Mooring Chains and Accessories

Materials and welding of offshore mooring chains and accessories for application in the stationkeeping system are to be in accordance with the ABS *Guide for the Certification of Offshore Mooring Chain*.

9 Fiber Ropes

For materials of synthetic fiber ropes for application in the stationkeeping system, the requirements specified in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring* are to be satisfied.

CHAPTER 3

General Design Requirements

CONTENTS

CHAPTER 3
General Design Requirements

SECTION 1
Design Considerations

1 General *(1 July 2020)*

The floating substructure, the stationkeeping system and onboard machinery, equipment and systems including applicable marine systems and associated equipment and machinery, safety systems and associated equipment, and lifesaving appliances and machinery are to be designed in compliance with the standards and requirements contained in this Guide with intention that the Floating Offshore Wind Turbine can fulfill its intended functions during its design life and meet specified minimum requirements for serviceability and operability.

Compliance of the tower with the design requirements in this Guide is required where (see 1-1/3):

- The optional **RNA** notation is requested by the Owner.
- The optional **RNA** notation is not requested by the Owner, but the tower and its connection to the RNA and/or to the floating substructure are not included in the wind turbine type certificate.

3 Safety Level *(1 July 2020)*

The design criteria specified in this Guide are intended for the unmanned Floating Offshore Wind Turbine having a safety level equivalent to the medium (L2) exposure level as defined in ISO 19904-1 for unmanned floating offshore structures.

The Floating Support Structure and the stationkeeping system can be categorized at various safety levels based on the consideration of life-safety and consequences of failure. Life-safety considers the most unfavorable combination of environmental event and turbine operating mode which would be expected to occur while personnel are on the Floating Offshore Wind Turbine. Consequences of failure deal with loss of life, environmental pollution, financial loss and potential negative impact to the industry.

Since the Floating Offshore Wind Turbine is typically unmanned and considered as having moderate consequences of failure, the Floating Support Structure can in general be designed to have a safety level equivalent to the medium (L2) exposure level as defined in ISO 19904-1. A higher safety level equivalent to the high (L1) exposure level as defined in ISO 19904-1 may be warranted when:

i) There is limited design and operation experience with floating offshore wind turbines.

ii) The Floating Support Structure is likely to have a low level of redundancy.

iii) The same or a similar design may be used in an entire offshore wind farm, which becomes vulnerable to "common-cause" failures.

For an offshore wind farm having multiple Floating Offshore Wind Turbines located in close proximity, failure of an individual stationkeeping system could potentially cause extensive damage to many other floating offshore wind turbines and power cables as well as other offshore installations in the offshore wind farm. The risk analysis may be used to determine the intended safety level of the stationkeeping system. However, the safety level of the stationkeeping system is not to be lower than that of the Floating Support Structure.

5 Design Life *(1 July 2020)*

The design life of the Floating Offshore Wind Turbine is not to be less than 20 years.

Upon the request by the Owner, a shorter design life may be accepted by ABS for the Floating Offshore Wind Turbine for the purpose of demonstrating viability of a new design concept or conducting pilot operations.

Continuance of classification beyond the design life is subject to the survey requirements specified in 11-2/23 and additional engineering analyses (see 1-1/7.3.2 and 1-1/7.5.2).

7 Environmental Conditions *(1 July 2020)*

The Floating Offshore Wind Turbine is to be designed to withstand specified operational and environmental conditions at the installation site while the RNA is in various operating conditions. The environmental conditions are defined in Chapter 4.

The Floating Offshore Wind Turbine is also to be designed for all pre-service operations such as load-out, transportation, installation, and commissioning.

Environmental conditions having a low probability of being exceeded where a mooring line or tendon of the stationkeeping system is broken or removed are also to be considered. Joint statistics may be used to determine a return period which, combined with the probability of occurrence of damage, produces a risk level consistent with the intended safety level.

Additionally, environmental conditions are to be specified for verifying the survivability of the Floating Offshore Wind Turbine . Survival environmental conditions are those that produce responses having a very low probability of being exceeded during the design life, and that the Floating Offshore Wind Turbine can endure such responses without causing catastrophic consequences.

9 Design Load Conditions and Load Calculations *(1 July 2020)*

The Floating Support Structure's life cycle phases, including the pre-service (load-out, transportation, installation, and commissioning) and in-service (operation, maintenance, and repair) phases, are to be investigated using anticipated loads. Permanent and variable loads together with relevant environmental loads due to the effects of wind, waves, currents, water level variations and, where deemed necessary, the effects of earthquake, temperature, fouling, ice, and other potential impacts are to be taken into account. Combinations of these loads as well as the turbine operating conditions that produce the most unfavorable local and global effects on the Floating Support Structure and the stationkeeping system, as determined by the requirements of the pre-service and in-service phases, are to be applied.

Dynamic analysis models are to be developed to predict design load effects for all relevant combinations of external site conditions and turbine operating conditions. A minimum set of such combinations, which is termed as Design Load Cases (DLCs), is defined in 5-2/3.

In addition to the Design Load Cases, other load cases are also to be considered for the situations where the Floating Offshore Wind Turbine is in the survival condition. The adequacy of air gap and stationkeeping capacity, as well as structural integrity if considered relevant, are to be verified by the robustness check, in which the Floating Offshore Wind Turbine is subjected to survival environmental conditions that are more severe than extreme design environmental conditions. The robustness check provides a direct indicator of the survivability of a specific design. A minimum set of Survival Load Cases (SLCs) is defined in 5-2/5.

When establishing design criteria for the Floating Offshore Wind Turbine, all applicable aspects contributing to the safety level need to be considered collectively. These include, but are not limited to

i) Prescribed safety factors

ii) Return period of extreme design environmental conditions

iii) Statistical variation of environmental conditions at different installation sites

iv) Load models of environmental and operational loading specific to offshore wind turbines

v) Strength and fatigue capacity models of materials, structural members, joints and foundation elements

vi) Characteristics of the responses of the offshore wind turbine

In contrast to bottom-founded offshore wind turbines, the Floating Offshore Wind Turbine having the typical hull types as defined in 1-1/15.1.1 through 1-1/15.1.4 shows a different pattern of sensitivity to the return period of environmental conditions. The minimum return period for the extreme storm condition, as specified in 5-2/3, is 50 years.

11 Global Performance Analyses *(1 July 2020)*

Global performance analyses of the Floating Offshore Wind Turbine are used to determine the global effects of environmental loads and other loads on the Floating Offshore Wind Turbine. Global response analyses are to be performed for each of the critical design phases.

Global performance analyses using various design load cases are required. It is recommended to include the turbine RNA and the tower, the floating substructure, the stationkeeping system, and, where relevant, the power cable system in an integrated (also known as "coupled") simulation model for global performance analyses. For those global loads and responses that are deemed as having weak coupling effects, global performance analyses may also be performed using a non-integrated model.

Either frequency or time domain methods, or a combination of both, may be used in global performance analyses. However, for those cases that have transient or highly nonlinear effects, time-domain analyses are normally required. Methods and models employed in analyses are to account for the relevant nonlinear and dynamic coupling effects of the RNA, the tower, the floating substructure, the stationkeeping system, and, where relevant, the power cable system.

Chapter 6 outlines specific requirements for global performance analyses of the Floating Offshore Wind Turbine.

13 Structural Design

The Floating Support Structure is to be designed in accordance with the requirements specified in Chapter 7. In the case where the structure's configuration or loading is not specifically addressed in this Guide, other recognized design standards may be used. Where alternative standards are followed, it is to be demonstrated that the safety level specified in this Guide has been adequately satisfied.

15 Stationkeeping System *(1 July 2020)*

The floating substructure is restrained by the stationkeeping system, which may be either a passive or an actively controlled system, or a combination of both. A passive stationkeeping system may be in the form of

- Spread mooring (catenary, taut-line or semi-taut-line),

- CALM consisting of a buoy and several catenary anchor legs,
- Turret mooring,
- SALM, such as an articulated leg, or
- Tension leg system.

An active system could be a mooring system with the ability of changing mooring line tensions.

17 Stability and Watertight/Weathertight Integrity *(1 July 2020)*

Adequacy of stability of the Floating Offshore Wind Turbine is to be verified for all relevant pre-service and in-service phases. The assessment of stability is to include the consideration of both intact and damaged conditions. The design requirements of Chapter 9 are to be satisfied.

19 Structural Material Selection, Welding and Connection *(1 July 2020)*

Structural materials are to be selected with consideration of the requirements for performance, welding and inspection. The materials used for the construction of the Floating Support Structure and the stationkeeping system are to be in accordance with the requirements of Chapter 2.

The welding of steel for the Floating Support Structure is to follow the requirements of Chapter 2. Special attention is to be given to the weld details for fatigue sensitive areas, whenever relevant. Refer to the ABS *Guide for the Fatigue Assessment of Offshore Structures*.

For connections other than welded joints, such as clamps, connectors and bolts that are used to join diagonal braces to the column or the turbine tower to the support foundation, the strength and fatigue resistance are to be assessed by analytical methods or testing following established industry practices such as those specified in the AISC *Steel Construction Manual*.

For concrete floating substructures, material and welding of steel reinforcement used for concrete construction are to comply with 2-1/3.13 of the ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbines*.

21 Corrosion Protection and Control *(1 July 2020)*

A corrosion protection and control system utilizing sacrificial anodes and/or coating in accordance with the recognized industry standards such as those published by NACE are to be provided. The design life of the corrosion protection and control system is to be in general the design life of the Floating Offshore Wind Turbine, unless a monitoring and repair plan is established. In the splash zone, corrosion allowance is to be added to the external shell plating. Reference may be made to the guidance on corrosion allowance in the relevant industry standards for floating offshore structures.

22 Consideration for Identical Floating Substructure Design *(1 July 2020)*

For the floating substructures of an identical design and supporting an identical RNA and tower combination, the stationkeeping system for these floating substructures could differ even in the same offshore wind farm. For design approval of these floating substructures, the extent of required design documentation submission and review may be adjusted by ABS with consideration of:

- Differences in environmental conditions and electrical power network conditions
- Difference in the load calculation for structural strength and fatigue assessment
- Difference in the motion and acceleration calculation
- Effect of modifications, if any, affecting class items
- Effect of variations in construction

25 Operating Manual *(1 July 2020)*

The Operating Manual, as required in 1-1/13.1, for the floating wind turbine is to be developed to specify the operating procedures and conditions that are consistent with the design information, criteria and limitations considered in the design of the Floating Offshore Wind Turbine.

CHAPTER 4

Environmental Conditions

CONTENTS

CHAPTER 4
Environmental Conditions

SECTION 1
Overview

1 General *(1 July 2020)*

Environmental conditions to which the Floating Offshore Wind Turbine is expected to be exposed during its design life are to be determined using adequate data for the areas in which the Floating Offshore Wind Turbine is to be transported and installed.

Environmental phenomena that influence the pre-service and in-service phases of the Floating Offshore Wind Turbine are to be described in terms of relevant characteristic parameters. Statistical data and realistic statistical and mathematical models which describe the range of expected variations of environmental conditions are to be employed. All data used are to be fully documented with the sources and estimated reliability of data noted.

Methods employed in developing available data into design criteria are to be described and submitted in accordance with 1-1/11.1. Probabilistic methods for short-term, long-term and extreme-value prediction are to employ statistical distributions appropriate to environmental phenomena under consideration, as evidenced by relevant statistical tests, confidence limits and other measures of statistical significance. Directional data and angular separation for wind, waves and currents are to be established. Hindcasting methods and models are to be fully documented if they are used to derive the environmental data.

Generally, suitable data and analyses supplied by recognized consultants will be accepted as the basis for design. For installations in areas where published design standards and data exist, such standards and data may be cited in the design documentation.

3 Environmental Factors to be Considered *(1 July 2020)*

In general, the design of the Floating Offshore Wind Turbine requires investigation of the following environmental factors.

i) Wind

ii) Waves

iii) Currents

iv) Tides, storm surges, and water levels

v) Air and sea temperatures

vi) Air density

vii) Ice and snow accumulation

viii) Marine growth

ix) Seismicity

x) Sea ice or lake ice

Other phenomena, such as tsunamis, submarine slides, seiche, abnormal composition of air and water, air humidity, salinity, ice drift, icebergs, ice scouring, etc., may require investigation depending upon specific conditions at an installation site and a specific design of the Floating Offshore Wind Turbine.

The investigation of seabed and soil conditions is described in 4-6/13.

CHAPTER 4
Environmental Conditions

SECTION 2
Wind

1 General

Statistical wind data are normally to include information on the frequency of occurrence, duration and direction of various wind speeds at the location where offshore wind turbines are to be installed. If on-site measurements are taken, the duration of individual measurements and the height above sea-level of measuring devices are to be stated. A wind speed value is only meaningful when qualified by its elevation and time-averaging duration.

In the absence of site data, published data and data from nearby land and sea stations may be used upon the agreement with ABS.

3 Wind Properties

3.1 Wind Speed and Turbulence

A wind condition is typically represented by a mean wind speed and a standard deviation of wind speed. The turbulence intensity, which measures the variation of wind speed relative to the mean wind speed, is defined as the ratio of the wind speed standard deviation to the mean wind speed (i.e., coefficient of variance of wind speed).

In this Guide, the mean wind speed, denoted as V_{hub}, at turbine hub height with 10-minute averaging duration is employed to define the design load conditions in Section 5-2 and to calculate the rotor generated aerodynamic loads and thrust forces as described in 5-3/3.

Mean wind speeds with 1-minute or 1-hour averaging time duration are used in the calculation of steady and dynamic wind forces exerted on exposed components of the Floating Support Structure, as described in 5-3/3.

Conversion of a mean wind speed from one averaging duration to another is to be based on site-specific wind conditions. Use of conversion factors in recognized industry standards appropriate to the installation site may be acceptable and is subject to approval by ABS.

For wind speeds given in terms of the "fastest mile of wind", V_f, the corresponding time-averaging period t in seconds is given by $t = 3600/V_f$, whereV_f is the fastest mile of wind at a reference height of 10 m (32.8 ft), in miles per hour.

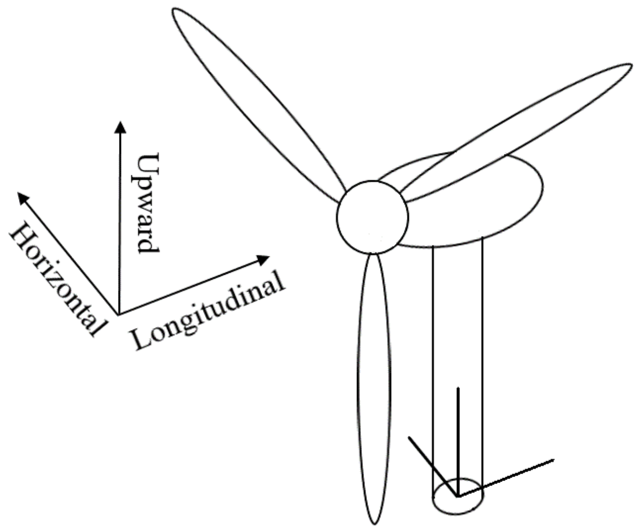
The turbulence of wind within 10 minutes is generally considered stationary and can be modeled by a power spectral density function and a coherence function. The turbulence model is to include the effects of varying wind speed, shears and directions and allow rotational sampling through varying shears. The three vector components of turbulent wind velocity, as depicted in 4-2/3.1 FIGURE 1 are defined as:

i) *Longitudinal* – Along the direction of the mean wind speed

ii) *Lateral* – Horizontal and normal to the longitudinal direction

iii) *Upward* – Normal to both the longitudinal and lateral directions and pointing upward

FIGURE 1
Vector Components of Turbulent Wind Velocity *(1 July 2020)*



3.3 Wind Profile *(1 July 2020)*

The mean wind speed profile (vertical wind shear) is to be defined by the power law:

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

where

$V(z)$	=	wind profile of the 10-minute mean wind speed as a function of height, z, above the Still Water Level (SWL), in m/s (ft/s)
V_{hub}	=	10-minute mean wind speed at turbine hub height, in m/s (ft/s)
α	=	power law exponent, values of which are given in 4-2/9 and 4-2/11, (dimensionless)
z	=	height above the SWL, in m (ft)
z_{hub}	=	hub height above the SWL, in m (ft)

The power law wind profile can also be applied to the mean wind speeds with 1-minute or 1-hour averaging duration, except that the exponent is to be determined based on site-specific conditions or using published data, such as those in the *FPI Rules*, as appropriate to the installation site.

For extratropical cyclone storm wind conditions, the mean wind speed profile may be represented by the following logarithmic wind shear law. It is expressed using the 1-hour mean wind speed at 10 m (32.8 ft) above the SWL.

$$V(z,t) = V(z,t_0)[1 - 0.41 I_u(z)\ln(t/t_0)] \quad \text{for} \quad t < t_0$$

where

$V(z,t)$	=	mean wind speed at height z and corresponding to an averaging time period t, in m/s (ft/s)
z	=	height above the SWL, in m (ft)
t	=	averaging time period shorter than $t_0 = 3600$ s, in seconds
$V(z,t_0)$	=	1-hour mean wind speed at height z, in m/s (ft/s)
	=	$V_0\left[1 + C\ln\left(\frac{z}{10\phi}\right)\right]$
t_0	=	reference averaging time period (1 hour), in seconds
	=	3600 s
C	=	$0.0573\sqrt{1 + 0.15V_0/\phi}$, (dimensionless)
V_0	=	1-hour mean wind speed at 10 m (32.8 ft) above the SWL, in m/s (ft/s)
$I_u(z)$	=	turbulence intensity, [i.e., the ratio of the wind speed standard deviation to the mean wind speed, at height z (dimensionless)]
	=	$0.06[1 + 0.043V_0/\phi]\left(\frac{z}{10\phi}\right)^{-0.22}$
ϕ	=	unit conversion factor (dimensionless)
	=	1 when using SI units (m, m/s)
	=	3.28 when using US Customary units (ft, ft/s)

For tropical cyclones (also termed as hurricanes or typhoons), the wind profile provided in Appendix A2-1 is to be applied.

For squalls, the wind profile recommended in API RP 2MET may be applied.

Other wind profile models may also be used provided that they can be justified by site-specific data.

3.5 Wind Spectrum and Spatial Coherence *(1 July 2020)*

Site-specific spectral density of wind speed and spatial coherence are preferable to be determined based on measured wind data.

When the site assessment is not available, the Mann uniform shear turbulence model or the Kaimal spectrum in combination with the exponential coherence model, as recommended in Annex C of IEC 61400-1 (2019), may be applied.

For the extratropical storm wind, the NPD (Frøya) wind spectrum in conjunction with the two-point coherence function provided in A1-1/3 may be applied.

For the tropical cyclone storm wind, the wind spectrum provided in A1-1/5 may be applied.

5 Long-Term and Extreme-Value Predictions

Long-term and extreme-value predictions for sustained and gust winds are to be based on recognized techniques and clearly described in the design documentation. Preferably, the statistical data used for the long-term distributions of wind speed are to be based on the same averaging periods of wind speeds as are used for the determination of loads.

7 Wind Conditions *(1 July 2020)*

A wind condition for the design of the Floating Offshore Wind Turbine is represented by a steady mean flow and an associated turbulence, as well as a mean wind direction and a change of the wind direction. The design wind conditions are further categorized into

i) The normal wind conditions, which occur more frequently than once per year;

ii) The extreme wind conditions representing rare wind conditions with a given return period; and

iii) The survival wind conditions having a very low probability of being exceeded during the design life of the Floating Offshore Wind Turbine.

The design wind conditions for the Floating Offshore Wind Turbine are specified in 4-2/9 through 4-2/13. The load case descriptions in Section 5-2 specify which wind condition is to be applied.

9 Normal Wind Conditions

9.1 Normal Wind Profile Model (NWP)

The normal mean wind speed profile (vertical wind shear) is to be defined by the power law specified in 4-2/3.3, where the power law exponent $\alpha = 0.14$.

9.3 Normal Turbulence Model (NTM) *(1 July 2020)*

The normal turbulence model (NTM) is to be applied together with the normal wind profile model (NWP) as defined in 4-2/9.1.

The standard deviation of turbulence of the normal turbulence model, denoted as σ_{NTM}, is defined as the 90% quantile in the probability distribution of wind speed standard deviation conditioned upon a given 10-minute mean wind speed at hub height (V_{hub}).

The value of the turbulence standard deviation is to be determined using appropriate statistical techniques applied to measured and preferably de-trended data. Where the site assessment is not available, the recommended approach provided in Section 6.4.3 of IEC 61400-3-1 (2019) may be used to estimate the standard deviation.

11 Extreme Wind Conditions

The extreme wind conditions are represented by peak wind speeds due to storms, extreme operating gust and turbulence, extreme wind shear events, and rapid changes in wind speed and direction.

11.1 Extreme Wind Speed Model (EWM) *(1 July 2020)*

The EWM is defined as a turbulent wind model with a specified return period. Both the 1-year and 50-year return extreme wind conditions are considered in the design load conditions as specified in Section 5-2.

When site data are not available, the wind profile of 10-minute mean wind speeds for the EWM with return periods of 1 year and 50 years, respectively, is to be represented by the power law model as follows:

$$V(z) = V_{hub}(z/z_{hub})^{0.11}$$

where

V_{hub}	=	10-minute mean wind speed at hub height, in m/s (ft/s)	
	=	$V_{10\min,1-\mathrm{yr}}$	for 1-year return extreme wind condition
	=	$V_{10\min,50-\mathrm{yr}}$	for 50-year return extreme wind condition
$V_{10\min,1-\mathrm{yr}}$	=	10-minute mean wind speed at hub height with a return period of 1 year, in m/s (ft/s)	
$V_{10\min,50-\mathrm{yr}}$	=	10-minute mean wind speed at hub height with a return period of 50 years, in m/s (ft/s)	
z	=	height above the SWL, in m (ft)	
z_{hub}	=	hub height above the SWL, in m (ft)	

The standard deviation of longitudinal turbulent wind speed of extreme wind condition, σ_1, at hub height is to be calculated as:

$$\sigma_1 = 0.11 \times V_{hub}$$

For the extratropical storm wind, the logarithmic wind shear law given in 4-2/3.3 may be used to calculate the wind profile and standard deviation of extreme wind conditions with a 50-year return period.

For the tropical cyclone storm wind, the wind profile, the standard deviation, the turbulence intensity, and the gust factor provided in Appendix A2-1 are to be applied.

Where applicable, extreme squall events with 1-year and 50-year return periods in time domain are to be considered as additional extreme wind conditions.

11.3 Extreme Operating Gust (EOG) *(1 July 2020)*

The EOG is represented by the hub height gust magnitude, V_{gust}, as defined in the following equation:

$$V_{gust} = \min\left\{1.35\left(V_{3\,\mathrm{sec},1-yr} - V_{hub}\right);\quad 3.3\left(\frac{\sigma_{NTM}}{1+0.1D/\Lambda_1}\right)\right\}$$

where

$V_{3\mathrm{sec},1-\mathrm{yr}}$	=	3-second mean wind speed at hub height with a return period of 1 year, in m/s (ft/s)	
V_{hub}	=	10-minute mean wind speed at hub height, as defined in 5-2/3.5 TABLE 1, in m/s (ft/s)	
σ_{NTM}	=	longitudinal turbulence standard deviation defined in 4-2/9.3, in m/s (ft/s)	
Λ_1	=	longitudinal turbulence length scale, in m (ft)	
	=	$0.7z$	when $z \le 60$ m (196.8 ft)
	=	42 m (137.8 ft)	when $z \ge 60$ m (196.8 ft)
D	=	rotor diameter, in m (ft)	

To account for possible resonance and interaction of gusts with the Floating Offshore Wind Turbine, gust events with longer durations are to be defined unless site-specific data shows that these events are unlikely to occur within the given return period. The time history of transient wind speed at height z is to be defined by:

$$V(z,t) = \begin{cases} V(z) - 0.37V_{gust}\sin(3\pi/T)[1-\cos(2\pi/T)] & 0 \le t \le T \\ V(z) & \text{otherwise} \end{cases}$$

where

$V(z)$	=	normal wind profile defined in 4-2/9.1, in m/s (ft/s)
z	=	height above the SWL, in m (ft)
T	=	10.5 s
	=	1.5 T_n
T_n	=	the natural period in seconds of the surge, sway, heave, roll, pitch, and yaw modes of the Floating Offshore Wind Turbine, in seconds. The natural period of the mode less than 7 seconds can be omitted

The amplitude for the EOG cannot be assumed to be constant with different time periods. When site data is not available, the hub-height gust magnitude, V_{gust}, may be replaced by the following:

$$V_{gust} = min\left\{1.35\left(V_{3sec,1-yr} - V_{hub}\right);\ 0.9Ln(T+1.18)\left(\frac{\sigma_{NTM}}{1+0.1D/\Lambda_1}\right)\right\}$$

11.5 Extreme Turbulence Model (ETM)

The ETM is to be represented by the normal wind profile (NWP) model specified in 4-2/9.1 and the turbulence whose standard deviation of longitudinal component is given by:

$$\sigma_1 = cI_{ref}\left[0.072\left(\frac{V_{ave}}{c}+3\right)\left(\frac{V_{hub}}{c}-4\right)+10\right]$$

where

c	=	2 m/s (6.56 ft/s)
V_{hub}	=	10-minute mean wind speed at hub height, as defined in 5-2/3.5 TABLE 1, in m/s (ft/s)
V_{ave}	=	site-specific annual mean wind speed at hub height, in m/s (ft/s)
I_{ref}	=	expected value of turbulence intensity at hub height when V_{hub} = 15 m/s (49.2 ft/s)

11.7 Extreme Direction Change (EDC) *(1 July 2020)*

The extreme direction change magnitude, θ_e, is to be calculated by:

$$\theta_e = \pm 4\arctan\left(\frac{\sigma_{NTM}}{V_{hub}(1+0.1D/\Lambda_1)}\right) \qquad -180° \le \theta_e \le 180°$$

where

σ_{NTM}	=	longitudinal turbulence standard deviation defined in 4-2/9.3, in m/s (ft/s)
V_{hub}	=	10-minute mean wind speed at hub height, as defined in 5-2/3.5 TABLE 1, in m/s (ft/s)
Λ_1	=	longitudinal turbulence length scale, defined in 4-2/11.3, in m (ft)
D	=	rotor diameter, in m (ft)

The time history of transient extreme direction change, $\theta(t)$, is defined by:

$$\theta(t) = \begin{cases} 0^\circ & t < 0 \\ \pm 0.5\theta_e[1 - \cos(\pi t/T)] & 0 \le t \le T \\ \theta_e & t > T \end{cases}$$

where $T = 6$ s is the duration of the extreme direction change. The sign in the equation is to be chosen such that the most unfavorable transient loading occurs. At the end of the time history of direction change, the direction is assumed to remain a constant value (θ_e). The wind speed is to follow the normal wind profile (NWP) model in 4-2/9.1.

In addition, time periods coinciding with the floating substructure yaw natural period are to be considered.

11.9 Extreme Coherent Gust with Direction Change (ECD) *(1 July 2020)*

The extreme coherent gust with direction change is to have a magnitude of:

$$V_{cg} = 15 \quad \text{m/s} \quad (49.21 \quad \text{ft/s})$$

The time history of transient wind speed at height z, is defined by:

$$V(z,t) = \begin{cases} V(z) & t < 0 \\ V(z) + 0.5V_{cg}[1 - \cos(\pi t/T)] & 0 \le t \le T \\ V(z) + V_{cg} & t > T \end{cases}$$

where

$V(z)$	=	normal wind profile defined in 4-2/9.1, in m/s (ft/s)
T	=	rise time of gust wind, in second
	=	10 s
	=	height above the SWL, in m (ft)

The rise in wind speed is assumed to occur simultaneously with the time history of direction change:

$$\theta(t) = \begin{cases} 0^\circ & t < 0 \\ \pm 0.5\theta_{cg}[1 - \cos(\pi t/T)] & 0 \le t \le T \\ \pm\theta_{cg} & t > T \end{cases}$$

where

θ_{cg}	=	magnitude of direction change, in degree
	=	$\begin{cases} 180^\circ & V_{hub} \le 4\text{m/s} \quad (13.12 \quad \text{ft/s}) \\ 720^\circ(V_{hub}/\phi)^{-1} & V_{hub} > 4\text{m/s} \quad (13.12 \quad \text{ft/s}) \end{cases}$
V_{hub}	=	10-minute mean wind speed at hub height, in m/s (ft/s)
T	=	rise time of gust wind, in second
	=	10 s
ϕ	=	unit conversion factor (dimensionless)
	=	1 when using SI units (m, m/s)
	=	3.28 when using US Customary units (ft, ft/s)

In addition, time periods coinciding with the floating substructure yaw natural period are to be considered.

11.11 Extreme Wind Shear (EWS)

The extreme wind shear is to be applied in both vertical and horizontal directions. The two extreme wind shears are considered independent events and therefore they are not to be applied simultaneously.

The time history of transient positive and negative vertical shear is given by:

$$V(z,t) = \begin{cases} V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \pm \left(\frac{z - z_{hub}}{D}\right)(2.5\phi + 0.2\beta\sigma_{NTM}(D/\Lambda_1)^{1/4}[1 - \cos(2\pi t/T)] & 0 \le t \le T \\ V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} & \text{otherwise} \end{cases}$$

The time history of transient horizontal shear is given by:

$$V(y,z,t) = \begin{cases} V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \pm \left(\frac{y}{D}\right)(2.5\phi + 0.2\beta\sigma_{NTM}(D/\Lambda_1)^{1/4}[1 - \cos(2\pi t/T)] & 0 \le t \le T \\ V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} & \text{otherwise} \end{cases}$$

where

V_{hub}	=	10-minute mean wind speed at hub height, as defined in 5-2/3.5 TABLE 1, in m/s (ft/s)
σ_{NTM}	=	longitudinal turbulence standard deviation defined in 4-2/9.3, in m/s (ft/s)
Λ_1	=	longitudinal turbulence length scale, defined in 4-2/11.3, in m (ft)
z	=	height above the SWL, in m (ft)
z_{hub}	=	hub height above the SWL, in m (ft)
y	=	horizontal distance from hub in the cross wind direction, in m (ft)
D	=	rotor diameter, in m (ft)
α	=	0.14, (dimensionless)
β	=	6.4, (dimensionless)
T	=	12 s
ϕ	=	unit conversion factor (dimensionless)
	=	1 when using SI units (m, m/s)
	=	3.28 when using US Customary units (ft, ft/s)

The sign for the transient wind shear is to be determined such that the most unfavorable transient loading occurs.

13 Survival Wind Conditions

The survival wind conditions are described by the Survival Wind Speed Model (SurWM).

13.1 Survival Wind Speed Model (SurWM)

The Survival Wind Speed Model (SurWM) is similar to the Extreme Wind Speed Model (EWM) defined in 4-2/11.1, but with a return period longer than 50 years, as specified in 5-2/5.

When site data are not available, the wind profile and turbulence spectrum for the SurWM is to be defined according to 4-2/3.3 and 4-2/3.5. When the wind profile is assumed to follow the power law, the power law exponent $\alpha = 0.11$ and the standard deviation of longitudinal turbulent wind speed is to be taken as $\sigma_1 = 0.11 \times V_{hub}$.

CHAPTER 4
Environmental Conditions

SECTION 3
Waves

1 General *(1 July 2020)*

The development of wave data is to reflect conditions at the installation site and the type of Floating Offshore Wind Turbine. Statistical wave data used to determine design parameters are normally to include the frequency of occurrence of various wave height groups, associated wave periods and directions. Published data and previously established design criteria for specific areas may be used where such exist. Hindcasting techniques that adequately account for shoaling and fetch limited effects on wave conditions at the site may be used to augment available data. Analytical wave spectra employed to augment available data are to reflect the shape and width of the data and to be appropriate to the general site conditions.

As applicable, wave data are to be developed in order to determine the following:

i) Dynamic responses of the Floating Support Structure and the stationkeeping system

ii) Maximum responses of structures and stationkeeping system components

iii) Fatigue

iv) Air gap

v) Wave impact on the local structure

All long-term and extreme value predictions employed for the determination of design wave conditions are to be fully described and based on recognized techniques. Because the wave-induced global responses may be increased due to the change of wave period and direction, consideration is to be given to waves of less than the maximum height but with a different period and/or direction. Waves that cause the most unfavorable effects on the overall structure may also differ from waves having the most severe effects on individual structural components. In addition to the most severe wave conditions, frequent waves of smaller heights are to be investigated to assess their effect on the fatigue and dynamic responses.

Swells can be of importance in conjunction with low-frequency responses of the Floating Offshore Wind Turbine. The potential bi-directional wave loading for the Floating Offshore Wind Turbine is to be taken into account.

The design wave conditions for the design of the Floating Offshore Wind Turbine are described below in 4-3/3 through 4-3/9. The design load conditions defined in Section 5-2 specify how these sea states are to be applied in combination with other design environmental conditions.

3 Normal Sea State (NSS)

The Normal Sea State (NSS) is represented by a significant wave height, a peak spectral period, and a wave direction. It is to be determined based on the site-specific long-term joint probability distribution of metocean parameters. The Normal Sea State (NSS) is used in 5-2/3.5 TABLE 1 to define a number of Design Load Cases (DLCs) requiring either strength analysis or fatigue analysis.

For strength analyses, the Normal Sea State (NSS) can be characterized by the expected value of significant wave height, $H_{s,NSS}$, conditioned upon a given value of V_{hub} (i.e., $H_{s,NSS} = \mathrm{E}[H_s | V_{hub}]$). A range of peak period, T_p, associated with each significant wave height is to be determined for load calculations. The resultant highest loads are to be used in the design of the Floating Support Structure.

For fatigue analyses, the number and resolution of sea states are to be determined in such a manner that the fatigue damage associated with the full long-term distribution of metocean parameters can be sufficiently accounted for.

5 Severe Sea State (SSS) *(1 July 2020)*

The Severe Sea State (SSS) condition is to be applied in combination with the normal wind condition, as specified in 4-2/9, and the turbine operating mode assumed in power production.

The Severe Sea State (SSS) is represented by a significant wave height, $H_{s,SSS}$, a peak spectral period and a wave direction. It is to be determined by extrapolation of site-specific long term joint probability distribution of metocean parameters to the extent that the joint occurrence of $H_{s,SSS}$ and a given 10-minute mean wind speed, V_{hub}, at hub height has a return period of 50 years. A series of V_{hub} is to be selected between the cut-in and cut-out wind speed for power production. As a conservative estimation, the 50-year return significant wave height independent of wind speed may be used to approximate $H_{s,SSS}$.

In the case that maximum operating sea states for the turbine in power production are pre-defined in the Operating Manual, those sea states may be used to determine $H_{s,SSS}$ in lieu of the requirements specified above.

A range of peak period associated with each significant wave height is to be determined for load calculations. The resultant most unfavorable responses are to be used in the design of the Floating Offshore Wind Turbine.

7 Extreme Sea State (ESS) *(1 July 2020)*

The Extreme Sea State (ESS) is to represent a 1-year return or 50-year return wave condition.

The significant wave height of the ESS model is denoted either as $H_{s,1-\mathrm{yr}}$ or $H_{s,50-\mathrm{yr}}$ for the extreme significant wave height with a return period of 1 year or 50 years, respectively. The values of $H_{s,1-\mathrm{yr}}$ and $H_{s,50-\mathrm{yr}}$ are to be determined from on-site measurements, hindcast data, or both for a specific installation site. Ranges of peak spectral periods appropriate to site-specific $H_{s,1-\mathrm{yr}}$ and $H_{s,50-\mathrm{yr}}$ respectively are to be determined for load calculations. The resultant most unfavorable responses for 1-year return conditions and 50-year return conditions, respectively, are to be used in the design of the Floating Offshore Wind Turbine.

The Extreme Sea State (ESS) is to be applied in combination with the Extreme Wind Model (EWM) defined in 4-2/11.1, the Extreme Current Model (ECM) defined in 4-4/5, and the Extreme Water Level Range Model (EWLR) defined in 4-5/5, with due consideration of their joint occurrence probabilities as required in 5-2/3.1.xiii.

9 Survival Sea State (SurSS)

The Survival Sea State (SurSS) condition is similar to the Extreme Sea State (ESS) defined in 4-3/7, but with a return period longer than 50 years, as specified in 5-2/5.

11 Breaking Waves *(1 July 2020)*

Where breaking waves are likely to occur at an installation site, the loads exerted by those breaking waves are to be assessed in the design. Breaking wave criteria are to be appropriate to the installation site and based on recognized methods. In shallow water, the empirical limit of wave height is approximately 0.78 times the local water depth. In deep water, the theoretical limit of wave steepness prior to breaking is 1/7. Further guidance on breaking wave hydrodynamics can be found in IEC 61400-3-1 (2019), Annex B.

CHAPTER 4
Environmental Conditions

SECTION 4
Currents

1 Currents *(1 July 2020)*

Data for currents are to include information on current speed, direction and variation with depth. The extent of information needed is to be commensurate with the expected severity of current conditions at the site in relation to other load causing phenomena, past experience in adjacent or analogous areas, and the type of the Floating Support Structure and the stationkeeping system to be installed. On-site data collection may be required for previously unstudied areas or areas expected to have unusual or severe conditions. Consideration is to be given to the following types of current, as appropriate to the installation site:

i) Wind-generated current

ii) Tide, density, circulation, and river-outflow generated sub-surface current

iii) Near shore, breaking wave induced surface currents running parallel to the coast

The direction of wind generated surface current velocity is assumed to be aligned with the wind direction.

Current velocity profiles with depth are to be based on site-specific data or recognized empirical relationships. Unusual profiles due to bottom currents and stratified effects due to river out-flow currents are to be accounted for. For the design of offshore wind turbines in U.S. offshore regions, the current profile is to be determined in accordance with Annex H, Annex I and Annex J of API RP 2MET.

The current models for the design of the Floating Offshore Wind Turbine are described below in 4-4/3 through 4-4/7. The design load conditions defined in Section 5-2 specify how the current models are to be applied in combination with other design environmental conditions.

3 Normal Current Model (NCM)

The Normal Current Model (NCM) is to be determined based on the long-term joint probability distribution of metocean parameters at the installation site.

For strength analyses, the Normal Current Model (NCM) is defined to represent the site-specific wind-generated current conditioned upon a given 10-minute mean wind speed at hub height (i.e., V_{hub}). Tide and storm-generated sub-surface currents are not included.

For fatigue analyses, the Normal Current Model (NCM) is to be determined in such a manner that the fatigue damage associated with the full long-term distribution of metocean parameters can be sufficiently accounted for.

5 Extreme Current Model (ECM)

The Extreme Current Model (ECM) is defined as the site-specific current with a return period of 1 year or 50 years.

The Extreme Current Model (ECM) is to be applied in combination with Extreme Wind Model (EWM) defined in 4-2/11.1, the Extreme Sea State (ESS) defined in 4-3/7, and the Extreme Water Level Range Model (EWLR) defined in 4-5/5, with due consideration of their joint occurrence probabilities as required in 5-2/3.1.xiii.

7 Survival Current Model (SurCM)

The Survival Current Model (SurCM) is similar to the Extreme Current Model (ECM) defined in 4-4/5, but with a return period longer than 50 years, as specified in Section 5-2.

CHAPTER 4
Environmental Conditions

SECTION 5
Tides, Storm Surges, and Water Levels

1 General *(1 July 2020)*

Tides can be classified as lunar or astronomical tides, wind tides, and pressure differential tides. The combination of the latter two is commonly called the storm surge. The water depth at any location consists of the mean depth, defined as the vertical distance between the sea floor and an appropriate near-surface datum, and a fluctuating component due to astronomical tides and storm surges. Astronomical tide variations are bounded by the highest astronomical tide (HAT) and the lowest astronomical tide (LAT). Storm surge is to be estimated from available statistics or by mathematical storm surge modeling. The still water level (SWL) referred in the air gap criterion is to be taken as the highest still water level (HSWL), which is defined as the sum of the highest astronomical level and the positive storm surge. Definitions of various water levels referred in this Guide are illustrated in 4-5/7 FIGURE 1.

For the TLP-type floating substructure (see 1-1/17.1.1), variations in the elevation of the daily tide may be used in determining the elevations of boat landings, barge fenders and the top of the splash zone for corrosion protection of structure. Water depths assumed for various types of analysis are to be clearly stated.

The water level models for the design of the Floating Offshore Wind Turbine are defined in 4-5/3 through 4-5/7. The design load conditions defined in Section 5-2 specify how the water level models are to be applied in combination with other design environmental conditions.

3 Normal Water Level Range (NWLR)

The Normal Water Level Range (NWLR) is defined as the variation in water level with a return period of one year.

Load calculations for strength load cases are to be performed based on the water level within the Normal Water Level Range (NWLR) in order to determine the most unfavorable responses. The influence of water level variation on fatigue loads is also to be considered, if deemed necessary.

5 Extreme Water Level Range (EWLR) *(1 July 2020)*

The Extreme Water Level Range (EWLR) with a return period of 50 years is to be determined. It is to be applied in the Design Load Cases (DLCs, see Section 5-2), where the Extreme Wave Model (EWM) with a return period of 50 years is applied.

Load calculations for strength load cases are to be performed based on the water level within the Extreme Water Level Range (EWLR) to determine the most unfavorable responses of the Floating Offshore Wind Turbine.

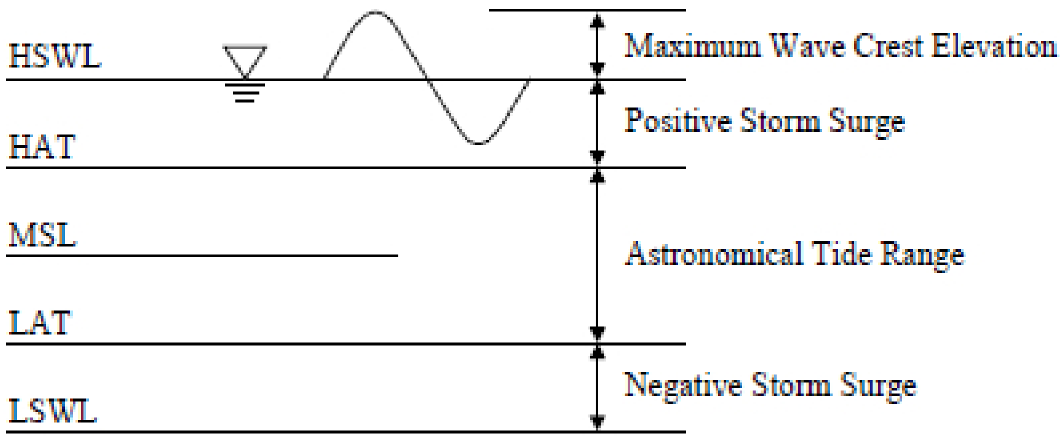
In the absence of the long term joint probability distribution of metocean parameters including water level, the following water levels are to be considered as a minimum:

- The Mean Sea Level (MSL), as defined in 1-1/17.3.16
- The highest still water level (HSWL), defined as a combination of highest astronomical tide (HAT) and positive storm surge, with a return period of 50 years
- The lowest still water level (LSWL), defined as a combination of lowest astronomical tide (LAT) and negative storm surge, with a return period of 50 years
- The water level associated with the highest breaking wave load, where applicable

7 Survival Water Level Range (SurWLR)

The Survival Water Level Range (SurWLR) is defined in a manner similar to the Extreme Water Level Range (EWLR) in4-5/5, but with a return period longer than 50 years, as specified in Section 5-2.

FIGURE 1
Definition of Water Levels



HSWL	Highest Still Water Level
HAT	Highest Astronomical Tide
MSL	Mean Sea Level (Mean Still Water Level)
LAT	Lowest Astronomical Tide
LSWL	Lowest Still Water Level

CHAPTER 4
Environmental Conditions

SECTION 6
Other Conditions

1 Temperature *(1 July 2020)*

Extreme values of air, sea and seabed temperatures are to be expressed in terms of return periods and associated highest and lowest values. Wind speed data are typically presented with respect to a specific reference temperature. Temperature data is also to be used to evaluate the selection of air density, structural materials, ambient ranges and conditions for machinery and equipment design, and for determination of thermal stresses, as relevant to the Floating Offshore Wind Turbine.

3 Air Density

The air density is to be measured in conjunction with the wind conditions at the installation site.

Where there are no site data for the air density, the value of air density is to be determined according to ISO 2533 and corrected as appropriate for annual average temperature at the installation site.

5 Ice and Snow Accumulation

For an installation site where ice and snow may accumulate, estimates are to be made of the extent to which ice and snow may accumulate. Data are to be derived from actual field measurements, laboratory data or data from analogous areas.

7 Marine Growth *(1 July 2020)*

Marine growth is to be considered in the design of the Floating Offshore Wind Turbine. Estimates of the rate and extent of marine growth may be based on past experience and available field data. Particular attention is to be paid to increases in hydrodynamic loading due to increased diameters and surface roughness of members caused by marine growth as well as to the added weight and increased inertial mass of submerged structural members, mooring components, and, export electrical cables. The types of marine growth likely to occur and their possible effects on corrosion protection coatings are also to be considered.

9 Seismicity and Earthquake Related Phenomena *(1 July 2020)*

The effects of earthquakes on the Floating Offshore Wind Turbine with the TLP-type floating substructure to be installed in areas known to be seismically active are to be taken into account.

9.1 Levels of Earthquake Conditions *(1 July 2020)*

The magnitudes of the parameters characterizing the earthquakes with return periods appropriate to the design life of the Floating Offshore Wind Turbine are to be determined. Two levels of earthquake conditions are to be considered to address the risk of damage and survivability.

i) *Strength Level.* Ground motion which has a reasonable likelihood of not being exceeded at the site during the design life of the Floating Offshore Wind Turbine.

ii) *Ductility Level.* Ground motion for a rare, intense earthquake to be applied to evaluate the risk of structural collapse.

9.3 Regional and Site-specific Data *(1 July 2020)*

The anticipated seismicity of an area is, to the extent practicable, to be established based on regional and site-specific data including, as appropriate, the following:

i) Magnitudes and recurrence intervals of seismic events

ii) Proximity to active faults

iii) Type of faulting

iv) Attenuation of ground motion between the faults and the site

v) Subsurface soil conditions

vi) Records from past seismic events at the site where available, or from analogous sites

9.5 Other Earthquake Related Phenomena *(1 July 2020)*

Seismic data are to be used to establish quantitative Strength Level and Ductility Level earthquake criteria describing the earthquake induced ground motion expected during the life of the Floating Offshore Wind Turbine. Both vertical and horizontal accelerations are to be considered for the design of the TLP-type floating substructure and the tendon system. In addition to ground motion, and as applicable to the site in question, the following earthquake related phenomena are to be taken into account.

i) Liquefaction of subsurface soils submarine slides

ii) Tsunamis

iii) Acoustic overpressure shock waves

11 Sea Ice or Lake Ice *(1 July 2020)*

For an installation site where ice hazards may occur, the effects of sea ice or lake ice on the Floating Offshore Wind Turbine are to be taken into account in the design. Depending on the ice conditions at the site, the Floating Offshore Wind Turbine may encounter moving ice and fast ice cover.

Statistical ice data of the site are to be used as the basis for deriving parameters such as ice thickness, ice crushing strength and pack ice concentration, etc., which are required for determining the ice loads.

Impact, both centric and eccentric, is to be considered where moving ice may impact the Floating Offshore Wind Turbine. Impact of smaller ice masses, which are accelerated by storm waves, and of large masses (multi-year floes and icebergs) moving under the action of current, wind, and Coriolis effect is to be considered in the design.

The interaction between ice and the Floating Offshore Wind Turbine produces mutual responses. This compliance is to be taken into account as appropriate.

13 Soil Conditions

Site investigation in general is to be in accordance with Section 3-2-5 of the ABS *Rules for Building and Classing Offshore Installations*. Soil data are to be taken in the vicinity of the anchor or tendon foundation site. An interpretation of such data is to be submitted by a recognized geotechnical consultant. To establish the soil characteristics of the site, the foundation system borings or probings are to be taken at all foundation locations to at least the anticipated depth of any pile or anchor penetrations plus a consideration for the soil variability. As an alternative, sub-bottom profile runs may be taken and correlated with at least two borings or probings in the vicinity of anchoring locations and an interpretation may be made by a recognized geotechnical consultant to adequately establish the soil profile at all anchoring locations.

15 Lightning *(1 July 2020)*

The lightning protection is to be designed in accordance with IEC 61400-24. It is not necessary for protective measures to extend to all parts of the Floating Offshore Wind Turbine, provided that safety is not compromised.

17 Electric Network Conditions *(1 July 2020)*

The assessment of electric network conditions is to be performed in accordance with IEC 61400-3-1 (2019).

CHAPTER 5
Loads

CONTENTS

CHAPTER 5
Loads

SECTION 1
Overview

1 General *(1 July 2020)*

This Section pertains to the identification, definition and determination of the loads which the Floating Offshore Wind Turbine may experience in its pre-service (load-out, transportation, installation, and commissioning) and in-service (operation, maintenance, and repair) phases. As appropriate to the planned Floating Offshore Wind Turbine , the types of loads described in 5-1/3 below are to be accounted for in the design.

3 Types of Loads to be Considered *(1 July 2020)*

Loads applied to the Floating Offshore Wind Turbine are categorized as permanent loads, variable loads and environmental loads.

3.1 Permanent Loads *(1 July 2020)*

Permanent loads are loads which do not change during the mode of operation under consideration. Permanent loads include, but are not limited to, the following.

i) Weight of rotor components (blades, hub, shaft, etc.) and equipment inside the nacelle (control and protection components, gearbox, drive train components, electrical generation components, cables, etc.)

ii) Weight of nacelle housing structure, Floating Support Structure, stationkeeping systems, fenders, ladders, corrosion protection system, and other permanent structures

iii) Weight of machinery, equipment and systems permanently installed on the floating substructure

iv) Weight of permanent ballast, if applicable

v) Permanent deformation and loads introduced during fabrication

vi) External hydrostatic pressure

vii) Pre-tension in mooring lines

viii) Static earth pressure

3.3 Variable Loads *(1 July 2020)*

Variable loads associated with the normal operation of a wind turbine are loads which may change during the mode of operation considered. Variable loads acting during the in-service phase include, but are not limited to, the following.

i) Forces exerted by lifting equipment during maintenance and repair

ii) Forces exerted on the Floating Support Structure by vessels moored to the structure or routine impact loads from a typical supply vessel that would normally service the offshore wind turbine

iii) Loads associated with helicopter operations, if applicable

iv) Loads associated with operations of an adjustable ballast system, if applicable

v) Actuation loads generated by wind turbine operations and controls including torque control from a generator or inverter, yaw and pitch actuator loads, and mechanical braking loads. The range of actuator forces is to be considered as appropriate in the calculation of response and loading. In particular, the range of friction, spring force or pressure for mechanical brakes is influenced by temperature and ageing, which are to be taken into account when calculating the response and loading during any brake event.

vi) Deformation loads due to deformation imposed on the Floating Support Structure and the stationkeeping system. The deformation loads include those due to temperature variations leading to thermal stress in the structure and, where necessary, loads due to soil displacements (e.g., differential settlement or lateral displacement) or due to deformations of adjacent structures. For concrete structures, deformation loads due to prestress, creep, shrinkage and expansion are to be taken into account.

Where applicable, the dynamic effects of the variable loads on the Floating Offshore Wind Turbine are to be considered.

Variable loads encountered during the pre-service phase are to be determined for each specific operation involved. The dynamic effects of such loads are also to be accounted for as necessary

3.5 Environmental Loads *(1 July 2020)*

Environmental loads are loads due to the action of wind, wave, current, ice, snow, earthquake and other environmental phenomena as described in Chapter 4. The characteristic parameters defining environmental loads are to be appropriate to the installation site and in accordance with the requirements specified in Chapter 4. The combination and severity of environmental conditions for the design of the Floating Offshore Wind Turbine are specified in Section 5-2. Calculations of environmental loads are described in Section 5-3.

Directionality is to be taken into account in the environmental criteria. Unless site-specific assessments provide evidence in support of a less stringent requirement, environmental loads are to be applied from directions producing the most unfavorable global or local effects on the Floating Support Structure or the stationkeeping system.

CHAPTER 5
Loads

SECTION 2
Design Load Conditions

1 General *(1 July 2020)*

Design load conditions for the design of the Floating Offshore Wind Turbine are to be represented by

i) Design Load Cases (DLCs), which are defined to verify the design adequacy of the Floating Offshore Wind Turbine subjected to the combination of turbine operational conditions, site-specific environmental conditions, electrical network conditions and other applicable design conditions, such as specific transportation, assembly, maintenance or repair conditions.

ii) Survival Load Cases (SLCs), which are defined to verify the survivability of the stationkeeping system and the adequacy of air gap when the Floating Offshore Wind Turbine is subjected to the environmental conditions that are more severe than the extreme design environmental conditions.

The above design load conditions are to be assessed for the design of the floating substructure and the stationkeeping system. The effect of the RNA and the tower on the floating substructure and the stationkeeping system is to be considered. Assessment of the tower design for the design load cases defined in this Chapter may be required (see 3-1/1).

The specifications of the load cases are given in the following Subsections.

3 Definition of Design Load Cases (DLCs)

3.1 General *(1 July 2020)*

All relevant DLCs with a reasonable probability of occurrence and covering the most significant conditions that the Floating Offshore Wind Turbine may experience are to be considered in the design.

As a minimum, the DLCs defined in 5-2/3.5 TABLE 1 are to be assessed in the design of the Floating Offshore Wind Turbine. Further requirements for the DLCs are specified in 5-2/3.3 for the Floating Support Structure and 5-2/3.5 for the stationkeeping system.

The DLCs specified in 5-2/3.5 TABLE 1 are adapted from "Table 2 – Design load cases" of IEC 61400-3-1 (2019) for bottom-founded offshore wind turbines, with various modifications to address unique load and response characteristics of the Floating Offshore Wind Turbine, and "Table 2 - FOWT specific design load cases" of IEC TS 61400-3-2 (2019) for Floating Offshore Wind Turbines.

Other design load cases are to be considered, whenever they are deemed relevant to a specific design. In particular, if correlation exists between an extreme environmental condition and a fault condition of the wind turbine, a realistic combination of the two is to be considered as an additional design load case.

Due consideration is also to be given to the effects of draft and trim variations as well as Vortex Induced Vibration (VIV) and Vortex Induced Motion (VIM) on the Floating Support Structure and the stationkeeping system.

For the Floating Offshore Wind Turbine to be deployed at an ice-infested offshore site, design load cases are to be specified to account for the effects of fast ice formation and moving ice (see 4-6/11) on the Floating Support Structure and the stationkeeping system.

For the Floating Offshore Wind Turbine equipped with active control systems, such as actively controlled ballast systems, stationkeeping systems with active tension adjustment, and seastate monitoring systems assisting in regulating turbine operations, the fault conditions of these systems that could adversely affect the Floating Offshore Wind Turbine are to be taken into account in the definition of the DLCs.

The descriptions and analysis requirements for DLCs defined in 5-2/3.5 TABLE 1, including the amendment to the original DLCs specified in IEC 61400-3-1 (2019) and IEC TS 61400-3-2 (2019), are presented as follows. Further reference is to be made to Section 7.4 and Section 7.5.4 of IEC 61400-3-1 (2019), and Section 7.4 and Section 7.5.4 of IEC TS 61400-3-2 (2019).

The following descriptions pertain to the required design load cases in 5-2/3.5 TABLE 1.

i) The DLC serial numbers are in general in accordance with those specified in IEC 61400-3-1 (2019) and IEC 61400-3-2 (2019).

ii) The DLCs defined in 5-2/3.5 TABLE 1 are for the design of the Floating Support Structure and the stationkeeping system of the Floating Offshore Wind Turbine. As such, DLC 1.1 required by IEC 61400-3-1 (2019) for the calculation of the ultimate loads acting on the RNA is not included in 5-2/3.5 TABLE 1.

iii) For "Power production plus occurrence of fault", DLC 2.5 is defined to address the event of low voltage ride through (LVRT), which is considered as a normal condition. The design low voltage ride through event is to be specified by voltage drop and duration. In addition, DLC 2.6 is defined to address fault of sea state limit protection system which is considered as an abnormal condition.

iv) As a new addition, DLC 4.3 is defined to address the normal shutdown process when the sea state exceeds the maximum operational limit as defined in the Operating Manual. Depending upon the requirement of the Operating Manual, the emergency stop may need to be considered instead of the normal shutdown.

v) The design environmental conditions referred in 5-2/3.5 TABLE 1 for wind, wave, current, and water level range are in accordance with the definitions specified in Chapter 4 of this Guide. Detailed references are listed in the table notes.

vi) Site-specific extreme wind speeds with various return periods are used to define the environmental conditions in DLC 6.1 to 6.4, DLC 7.1 and 7.2, and DLC 8.2 and 8.3 in 5-2/3.5 TABLE 1. This differs from IEC 61400-3-1 (2019) where definitions of these DLCs are related to RNA's Reference Wind Speed (V_{ref}) and the conversion factors are prescribed for different return periods.

vii) Currents are to be considered in the fatigue design load cases.

viii) The return period chosen for the extreme environmental conditions of DLC 6.1 and DLC 6.2 and for the severe wave conditions of DLC 1.6 is generally not to be less than 50 years.

ix) DLC 6.2 assumes a loss of connection to electrical power network at an early stage of the storm containing the extreme wind conditions. A nacelle yaw misalignment ranging between –180° and +180° is generally required to be considered in DLC 6.2. Load calculations are to be based on the misalignment angle that results in the most unfavorable responses in the Floating Offshore Wind Turbine. The range of yaw misalignment may be reduced to account for the contribution from an active or passive yaw control system, provided that the designer can justify that

- Such a system is capable of achieving the assumed reduction of yaw misalignment under site-specific conditions; and
- An appropriate monitoring and maintenance program is implemented to maintain the effectiveness of yawing control during the design life of the Floating Offshore Wind Turbine.

x) For those load cases, including DLC 1.6, DLC 6.1, 6.2, 6.3, 7.1 and 8.2, which in general require time domain dynamic simulations for the combined turbulent wind and stochastic storm waves, the simulation time duration may differ from the reference periods of wind speed and significant wave height. The extreme responses determined for the wave condition used in the simulation are to be equivalent to those obtained from 3-hour simulations.

IEC 61400-3-1 (2019), Section 7.5.6 recommends at least six 1-hour constrained wave simulations be performed. Other approaches may be taken if the estimated extreme response is shown not less than that obtained with 1-hour realizations.

Depending upon the type of the Floating Support Structure and the stationkeeping system of a specific design as well as site conditions, other simulation time durations may need to be used along with an appropriate adjustment to the wind model and/or wave model such that the extreme responses can be adequately estimated. Additional requirements of time domain analyses are provided in Section 6-2.

xi) Where a wind speed range is indicated in 5-2/3.5 TABLE 1, wind speeds leading to the most unfavorable responses are to be considered for the design of the Floating Offshore Wind Turbine. When the range of wind speeds is represented by a set of discrete values, the interval between two adjacent discrete wind speeds is not to be greater than 2 m/s (6.6 ft/s), In addition, the turbine Rated Wind Speed (V_r, see 1-1/17.3.24), where applicable, is to be included as one of the discrete wind speeds used in the load calculation.

xii) If site-specific directional data are not available, the direction of applied environmental conditions is to be determined to produce the most unfavorable effect on the Floating Offshore Wind Turbine. For DLC 6.1, 6.2, 6.3, 7.1 and 8.2, the misalignment between wind and wave directions is to be considered up to 90°for extreme environmental conditions governed by tropic cyclones.

For single point mooring systems such as a turret mooring system, a heading analysis can be performed with consideration of directionality of site-specific wave, wind, and current conditions. When site-specific directional data are not available, the directional combination in 3/3.5.6 of the ABS *Guide for Position Mooring Systems is to be considered*.

xiii) Extreme metocean conditions in a specific load case (e.g., DLC 6.1, 6.2, 6.3, 7.1 and 8.2) are formed by combining the extreme wind (EWM), the extreme wave (ESS), the extreme current (ECM), and the extreme water level range (EWLR). The probability of joint occurrence of these environmental parameters is to be taken into account when establishing extreme metocean conditions. Consideration is to be given to the peak wind, peak wave and peak current condition (see, e.g., API RP 2MET, 2019, as appropriate to site conditions and a specific design of the Floating Offshore Wind Turbine. Combining all individual extremes with the same return period is normally a conservative approach.

xiv) For those DLCs denoted by ‘S’ in the ‘Type of Analysis’ column in 5-2/3.5 TABLE 1 for the structural strength design, the effect of environmental loads are to be combined with the effect of permanent loads and variable loads (see 5-1/3). Combinations of the load effects that produce the most severe local and global effects on the Floating Support Structure and/or the stationkeeping system as determined by the requirements of the pre-service and in-service phases, as well as different nature of structures, are to be used.

xv) The description for DLC 8.x is revised to 'Temporary (Load-out, transportation, installation, maintenance and repair)'.

Design environmental conditions for transportation (dry-tow) are to be based on a 10-year return period for conditions along the selected transit route, unless a weather routing plan is implemented for the voyage. For field transit (wet-tow), environmental conditions specified by the Owner, normally with a return period of 1 year, may be applied.

For other 'Temporary' operations, the return period of design environmental conditions may be as specified by the Owner. The Owner is responsible for assuring that operational plans and environmental monitoring for these temporary phases are compatible with the environmental conditions used in the design.

xvi) A new DLC 8.2 is added to account for the fatigue damage occurred during the temporary phase. The serial numbers of the subsequent DLCs are revised accordingly.

xvii) Wind and wave directionality for DLC 1.3, 1.5, 1.6 and 8.3 is to consider the misalignment of wind and wave directions. If site-specific directional data are not available, the direction of applied environmental conditions is to produce the most unfavorable effect on the Floating Support Structure.

xviii) For power production, additional design load cases DLC 9.1, 9.2 and 9.3 are adapted from IEC TS 61400-3-2 with some modifications. For the parked (standing still or idling) condition, additional design load cases DLC 10.1, 10.2 and 10.3 are adapted from IEC TS 61400-3-2 with some modifications.

The NTM wind model is used in combination with severe sea state (SSS) for DLC 9.1 and DLC 9.2. The extreme wind model (EWM) is used in combination with extreme sea state (ESS) with 1-year return period for DLC 10.3 according to damage stability requirements.

DLC 9.1 and 10.1 address a transient situation between the intact condition (all mooring lines or tendons are intact) and the condition after the loss of one mooring line or tendon.

DLC 9.2 and 10.2 address the situation after one mooring line or tendon breaks and the structure has reached a new mean position.

The damaged condition with one broken line is to be assessed in accordance with DLC 9.1, 9.2, 10.1 and 10.2 for the redundant mooring system (see 8-1/9). For the TLP tendon made up of steel tubulars, DLC 9.1, 9.2, 10.1 and 10.2 are not applicable.

DLC 9.3 and 10.3 address the situation for floating substructure with more than one compartment to evaluate flooding conditions according to damage stability requirements.

xix) For each DLC, if a possible wind, wave, swell, and current misalignment can lead to higher loading for the Floating Offshore Wind Turbine, this misalignment is to be considered.

xx) For guidance on the suggested number and length of simulations, refer to Section 10 of the ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbines*.

3.3 DLCs for Floating Support Structures *(1 July 2020)*

5-2/3.1 is to be consulted for the requirements of the DLCs.

For each DLC defined in 5-2/3.5 TABLE 1, the 'Type of Analysis'is denoted 'S'for the strength analysis or 'F' for the fatigue analysis. Results of the strength analysis are used in the structural assessment against acceptance criteria pertaining to the yielding and buckling. Results of the fatigue analysis are used in the structural assessment against criteria pertaining to fatigue performance.

Those DLCs indicated with 'S', are further classified as *i)* 'N' representing normal design conditions, which are expected to occur frequently during the design life of the Floating Offshore Wind Turbine. The corresponding operational mode of the turbine is in a normal state or with minor faults or abnormalities.

ii) 'A' representing abnormal design conditions, which are less likely to occur than normal design conditions. They usually correspond to design conditions with severe faults that result in activation of system protection functions.

iii) 'T' representing the design conditions relevant to temporary operations including load-out, transportation, installation, maintenance and repair of the Floating Offshore Wind Turbine.

The type of design conditions, 'N', 'A', or 'T', determines the safety factors in the strength design criteria to be applied to the Floating Support Structure. The safety factors referred in 5-2/3.5 TABLE 1 are specified in Section 7-2.

3.5 DLCs for Stationkeeping Systems *(1 July 2020)*

5-2/3.1 is to be consulted for the requirements of the DLCs.

The DLCs specified in 5-2/3.5 TABLE 1 are to be applied, as a minimum, to the design of the stationkeeping system.

Additional load cases are to be considered, whenever they are deemed relevant to the integrity of the stationkeeping system. These additional load cases are to include, but are not limited to, consideration of the following conditions, where applicable.

i) Global yawing moment exerted on the Floating Support Structure due to unbalanced rotor aerodynamic loads caused by the shade effect or the wake effect of neighboring floating offshore wind turbines

ii) Vortex Induced Motion (VIM) of the floating substructure due to the site current conditions established in accordance with 4-4/1

iii) Vortex Induced Vibration (VIV) fatigue due to the site-specific current condition established in accordance with 4-4/1

iv) Earthquake-induced foundation movements on the design of the tendon system for the TLP-type floating substructure located in seismically active areas (see 4-6/9)

v) Where the tendon is designed to be subject to planned replacement, the temporary removal of one tendon line is to be analyzed using DLC 6.1 along with the 5-year return extreme environmental conditions.

The safety factors for the stationkeeping system design are specified in Chapter 8 of this Guide. The association between safety factors and the designation 'N', 'A' and 'T' representing turbine operating conditions, as described in 5-2/3.3 for the design of the Floating Support Structures, are not applicable to the stationkeeping system design.

TABLE 1
Design Load Cases (1 July 2020)

Turbine Condition	*DLC*	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*	*Other Conditions*	*Type of Analysis*	*Safety Factor*
1) Power production	1.2	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or ≥ MSL		F	FDF
	1.3	ETM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_s = E[H_s \mid V_{hub}]$	MIS, MUL	NCM	MSL		S	N
	1.4	ECD $V_{hub} = V_r \pm 2\,\mathrm{m/s}$ $(6.6\,\mathrm{ft/s})$	NSS $H_s = E[H_s \mid V_{hub}]$	MIS, wind direction change	NCM	MSL		S	N
	1.5	EWS $V_{in} \le V_{hub} \le V_{out}$	NSS $H_s = E[H_s \mid V_{hub}]$	MIS, MUL	NCM	MSL		S	N
	1.6	NTM $V_{in} \le V_{hub} \le V_{out}$	SSS $H_s = H_{s,SSS}$	MIS, MUL	NCM	NWLR		S	N

Turbine Condition	*DLC*	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*	*Other Conditions*	*Type of Analysis*	*Safety Factor*
2) Power production plus occurrence of fault	2.1	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_S = E[H_S \mid V_{hub}]$	COD, UNI	NCM	MSL	Normal control system fault or loss of electrical network or primary layer control function fault	S	N
	2.2	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_S = E[H_S \mid V_{hub}]$	COD, UNI	NCM	MSL	Abnormal control system fault or secondary layer protection function related fault	S	A
	2.3	EOG $V_{hub} = V_r \pm 2\,\mathrm{m/s}$ $(6.6\,\mathrm{ft/s})$ and V_{out}	NSS $H_S = E[H_S \mid V_{hub}]$	COD, UNI	NCM	MSL	External or internal electrical fault including loss of electrical network	S	A
	2.4	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_s = E[H_s \mid V_{hub}]$	COD, UNI	NCM	NWLR or ≥ MSL	Control system fault, electrical fault or loss of electrical network	F	FDF
	2.5	NWP $V_{in} \le V_{hub} \le V_{out}$	NSS $H_s = E[H_s \mid V_{hub}]$	COD, UNI	NCM	NWLR	Low voltage ride through	S	A
	2.6	NTM $V_{in} \le V_{hub} \le V_{out}$	SSS $H_s = H_{s,SSS}$	MIS, MUL	NCM	NWLR	Fault of sea state limit protection system	S	A

Turbine Condition	*DLC*	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*	*Other Conditions*	*Type of Analysis*	*Safety Factor*
3) Start-up	3.1	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	NWLR or ≤ MSL		F	FDF
	3.2	EOG $V_{hub} = V_{in}$, $V_r \pm 2$ m/s (6.6 ft/s) and V_{out}	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		S	N
	3.3	EDC $V_{hub} = V_{in}$, $V_r \pm 2$ m/s (6.6 ft/s) and V_{out}	NSS $H_s = E[H_s \| V_{hub}]$	MIS, wind direction change	NCM	MSL		S	N
4) Normal shutdown	4.1	NTM $V_{in} \le V_{hub} \le V_{out}$	NSS $H_S = E[H_S \| V_{hub}]$	COD, UNI	NCM	NWLR or ≥ MSL		F	FDF
	4.2	EOG $V_{hub} = V_r \pm 2\,\mathrm{m/s}$ $(6.6\,\mathrm{ft/s})$ and V_{out}	NSS $H_S = E[H_S \| V_{hub}]$	COD, UNI	NCM	MSL		S	N
	4.3	NTM $V_{in} \le V_{hub} \le V_{out}$	SSS H_S = maximum operating limit	COD, UNI	NCM	NWLR	sea state exceeding the maximum operational limit	S	N
5) Emergency stop	5.1	NTM $V_{hub} = V_r \pm 2\,\mathrm{m/s}$ $(6.6\,\mathrm{ft/s})$ and V_{out}	NSS $H_S = E[H_S \| V_{hub}]$	COD, UNI	NCM	MSL		S	N

Turbine Condition	*DLC*	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*	*Other Conditions*	*Type of Analysis*	*Safety Factor*
6) Parked (standing still or idling)	6.1	EWM $V_{hub} = V_{10\text{min}, 50-\text{yr}}$	ESS $H_s = H_{s, 50-\text{yr}}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level		S	N
	6.2	EWM $V_{hub} = V_{10\text{min}, 50-\text{yr}}$	ESS $H_s = H_{s, 50-\text{yr}}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level	Loss of electrical network	S	A
	6.3	EWM $V_{hub} = V_{10\text{min}, 1-\text{yr}}$	ESS $H_s = H_{s, 1-\text{yr}}$	MIS, MUL	ECM 1-yr Current	NWLR	Extreme yaw misalignment	S	N
	6.4	NTM $V_{hub} \leq V_{10\text{min}, 1-\text{yr}}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or ≥ MSL		F	FDF
7) Parked and fault conditions	7.1	EWM $V_{hub} = V_{10min, 1-yr}$	ESS $H_s = H_{s, 1-yr}$	MIS, MUL	ECM 1-yr Current	NWLR		S	A
	7.2	NTM $V_{hub} \leq V_{10\text{min}, 1-\text{yr}}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or ≥ MSL		F	FDF
8) Temporary (Load-out, transportation, installation, maintenance and repair)	8.1	To be defined by the Fabricator or Owner						S	T
	8.2	EWM $V_{hub} = V_{10\text{min}, 1-\text{yr}}$	ESS $H_s = H_{s, 1-\text{yr}}$	MIS, MUL	ECM 1-yr Current	NWLR		S	A
	8.3	NTM $V_{hub} \leq V_{10\text{min}, 1-\text{yr}}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or ≥ MSL	No grid during installation period	F	FDF

Turbine Condition	*DLC*	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*	*Other Conditions*	*Type of Analysis*	*Safety Factor*
	8.4	To be defined by the Fabricator or Owner						F	FDF
9) Power production	9.1	NTM $V_{in} \leq V_{hub} \leq V_{out}$	SSS $H_s = H_{s,SSS}$	MIS, MUL	NCM	NWLR	Transient condition between intact and redundancy check condition	S	A
	9.2	NTM $V_{in} \leq V_{hub} \leq V_{out}$	SSS $H_s = H_{s,SSS}$	MIS, MUL	NCM	NWLR	Redundancy check condition	S	A
	9.3	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	MIS, MUL	NCM	MSL	Leakage (damage stability)	S	A
10) Parked (standing still or idling)	10.1	EWM $V_{hub} = V_{10min,50\text{-}yr}$	ESS $H_s = H_{s,50\text{-}yr}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level	Transient condition between intact and redundancy check condition	S	A
	10.2	EWM $V_{hub} = V_{10min,50\text{-}yr}$	ESS $H_s = H_{s,50\text{-}yr}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level	Redundancy check condition	S	A
	10.3	EWM $V_{hub} = V_{10min,1\text{-}yr}$	ESS $H_s = H_{s,1\text{-}yr}$	MIS, MUL	ECM 1-yr Current	NWLR	Leakage (damage stability)	S	A

Notes:

1. The descriptions of the design load cases in the table are provided in 5-2/3.1.
2. The symbols and abbreviations used in the table are summarized as follows.

COD	co-directional (aligned) wind and wave direction	F	fatigue (5-2/3.3)
DLC	design load case	S	strength (5-2/3.3)
ECD	extreme coherent gust with direction change (4-2/11.9)	N	normal (5-2/3.3)

ECM	extreme current model (4-4/5)
EDC	extreme direction change (4-2/11.7)
EOG	extreme operating gust (4-2/11.3)
ESS	extreme sea state (4-3/7)
ETM	extreme turbulence model (4-2/11.5)
EWLR	extreme water level range (4-5/5)
EWM	extreme wind speed model (4-2/11.1)
EWS	extreme wind shear (4-2/11.11)
MIS	misaligned wind and wave directions
MSL	mean sea level (4-5/7 FIGURE 1)
MUL	multi-directional wind and wave
NCM	normal current model (4-4/3)
NTM	normal turbulence model (4-2/9.3)
NWLR	normal water level range (4-5/3)
NWP	normal wind profile model (4-2/9.1)
NSS	normal sea state (4-3/3)
SSS	severe sea state (4-3/5)
UNI	uni-directional wind and wave directions

A	abnormal (5-2/3.3)
T	temporary (5-2/3.3)
FDF	fatigue design factor (Chapter 7 and Chapter 8)
H_S	significant wave height
$H_{S,1-\mathrm{yr}}$	significant wave heights with a return period of 1-year (4-3/7)
$H_{S,50-\mathrm{yr}}$	significant wave heights with a return period of 50-year (4-3/7)
$H_{S,SSS}$	significant wave height of the severe sea state (4-3/5)
T_p	peak period of wave spectrum
$V_{10\mathrm{min},1-\mathrm{yr}}$	10 minute mean wind speed at hub height with a return period of 1 year (4-2/11)
$V_{10\mathrm{min},50-\mathrm{yr}}$	10 minute mean wind speed at hub height with a return period of 50 year (4-2/11)
V_{hub}	10-minute mean wind speed at hub height (4-2/3.1)
V_{in}	cut-in wind speed (1-1/17.3.3)
V_{out}	cut-out wind speed (1-1/17.3.4)
V_r	rated wind speed (1-1/17.3.24)

$V_r \pm 2\,\mathrm{m/s}(6.6\,\mathrm{ft/s})$ Sensitivity to the wind speeds in the range is to be analyzed (5-2/3.1)

5 Definition of Survival Load Cases (SLCs) *(1 July 2020)*

The Survival Load Cases (SLCs) are used for the robustness check of the stationkeeping system and the air gap (also known as deck clearance or freeboard).

As a minimum, the SLCs specified in 5-2/5 TABLE 2 are to be assessed in the robustness check of the Floating Offshore Wind Turbine. The probability of joint occurrence of environmental parameters are to be taken into account when establishing survival metocean conditions, with the consideration of the peak wind, peak wave and peak current condition (see, e.g., API RP 2MET). The effect of environmental loads is to be combined with the effect of permanent loads and variable loads. Combinations of the load effects that produce the most unfavorable effects on the stationkeeping system or the air gap are to be used to assess the design adequacy.

The safety factors applicable for the survival load case are described in Chapter 8. The differentiation of 'N', 'A' and 'T' turbine operating conditions is not applicable to the survival load cases.

For the TLP-type floating substructure, additional robustness checks of its stationkeeping system are to include

i) The assessment of the minimum tendon tension for the Floating Offshore Wind Turbine subjected to the SLCs defined in 5-2/5 TABLE 2;

ii) The strength assessment of the 'one-tendon removed' case, if applicable, for the Floating Offshore Wind Turbine carrying the parked RNA and subjected to a 50-year return extreme environmental condition; and

iii) The fatigue life assessment of the tendon system, in accordance with API RP 2T, for the Floating Offshore Wind Turbine carrying the parked RNA and subjected to a single extreme environmental event with a return period of 50 years.

TABLE 2
Survival Load Cases *(1 July 2020)*

Design Condition	*Wind Condition*	*Waves*	*Wind and Wave Directionality*	*Sea Currents*	*Water Level*
Parked RNA; Intact Blades; Intact Hull and Stationkeeping System	SurWM $V_{hub} = V_{10\mathrm{min,\,n-yr}}$	SurSS $H_s = H_{s,\mathrm{n-yr}}$	MIS, MUL	SurCM n-yr Currents	SurWLR n-yr Water Level
Parked RNA; Damaged Blade(s); Intact Hull and Stationkeeping System	SurWM $V_{hub} = V_{10\mathrm{min,\,500-yr}}$	SurSS $H_s = H_{s,\mathrm{500-yr}}$	MIS, MUL	SurCM 500-yr Currents	SurWLR 500-yr Water Level

Notes:

1 'Parked RNA, Damaged Blade(s); Intact Hull and Stationkeeping System' case is to be assessed if one turbine blade or multiple turbine blades cannot remain intact under the storm wind condition with a return period of 500 years (i.e. n < 500 years)

2 The symbols and abbreviations used in the table are summarized as follows

n-yr — maximum return period (n years) of the storm wind condition that turbine blades can sustain and remain intact or 500 years, whichever is less

$H_{s,n\text{-}yr}$ — significant wave height with a return period of n years

$H_{s,500\text{-}yr}$	significant wave height with a return period of 500 years
$V_{10min,n\text{-}yr}$	10 minute mean wind speed at hub height with a return period of *n* years
$V_{10min,500\text{-}yr}$	10 minute mean wind speed at hub height with a return period of 500 years
SurWM	survival wind model (4-2/13)
SurSS	survival sea state (4-3/9)
SurCM	survival current model (4-4/7)
SurWLR	survival water level range (4-5/7)

Other symbols and abbreviations used in the table are defined in the Notes of 5-2/Table 1.

CHAPTER 5
Loads

SECTION 3
Determination of Environmental Loads

1 General *(1 July 2020)*

Environmental loads are to be determined using analytical methods compatible with the environmental condition models established in compliance with Chapter 4. Recognized load calculation methods are to be employed that are proven sufficiently accurate in practice, and are shown to be appropriate to the characteristics of the Floating Offshore Wind Turbine and site conditions.

Model or on-site test data can also be employed to establish environmental loads.

3 Wind Loads *(1 July 2020)*

Wind loads and local wind pressures are to be determined based on analytical methods or wind tunnel tests using a representative model of the Floating Offshore Wind Turbine . Static and dynamic wind load effects generated directly by inflowing wind and indirectly by the wind generated motions of the Floating Offshore Wind Turbine and turbine operations are to be taken into account.

3.1 Aerodynamic Loads Generated by the Rotor *(1 July 2020)*

Aerodynamic loads induced by airflow passing through the rotor are determined by the mean wind speed and turbulence across the rotor plane, rotor rotational speed, air density, and aerodynamic shapes of wind turbine components, as well as interactive effects such as aero-elasticity and rotational sampling. Aerodynamic loads due to these effects are to be calculated using recognized methods and computer programs.

The 10-minute mean wind speed at hub height, (i.e., V_{hub} as defined in 4-2/3.1), and the wind models defined in Section 4-2 are used in the definition of design load conditions in Section 5-2.

For floating offshore wind turbines installed in a wind farm, the potential shadow effect and wake effect on the loads are to be considered for both the strength and fatigue analyses. For large wind farms, an increase in the turbulence intensity or terrain roughness is to be taken into account. The mutual influence of wind turbines through the wake interaction behind the rotor is to be considered up to a distance of 10 times of rotor diameter. Refer to IEC 61400-1 for the guidance on the wake effects from neighboring wind turbines.

3.3 Rotor Thrust Force

For the purpose of calculating the overturning moment in the stability analysis (see Section 9-2), the overturning moment due to quasi-static wind load on turbine RNA may be calculated using the thrust coefficient, C_T, determined by the rotor properties, control algorithm and turbine operating conditions. The thrust force generated by wind perpendicular to the swept area of the blades may be estimated by the following equation:

$$F_{thrust} = (\rho_a/2)C_T A_{thrust} V_{hub}^2$$

where

F_{thrust}	=	wind drag load, in N (lbf)
ρ_a	=	mass density of air, in kg/m^3 (Slug /ft^3)
C_T	=	thrust coefficient (dimensionless)
A_{thrust}	=	swept area of the blades, in m^2 (ft^2)
V_{hub}	=	10-minute mean wind speed at hub height, in m/s (ft/s)

3.5 Wind Forces on Exposed Structural Components

For wind pressure normal to flat surfaces, such as nacelle and exposed above-water components of the Floating Support Structure, or normal to the axis of members not having flat surfaces, such as the tower, the wind loading can be considered either as a steady wind force or as a combination of steady and time-varying force, as described below:

i) When wind force is considered as a constant (steady) force, the wind velocity based on the 1-minute mean wind speed is to be used for calculating the wind load.

ii) Effect of the wind spectrum can be taken into account by considering wind loading as a combination of steady load and a time-varying component calculated from a suitable wind spectrum. API RP 2T provides further guidance on calculating the dynamic component of wind force on exposed structures. For this approach, the wind velocity based on 1-hour mean wind speed is used for calculating the steady wind force. The first approach is preferred to this approach when the wind energy spectrum cannot be derived with confidence.

The following relation is to be used for calculating the steady wind force when using the first approach described above:

$$F_{wind} = (\rho_a/2)C_s A_{wind} V_{wind}^2$$

where

F_{wind}	=	steady wind force, in N (lbf)
ρ_a	=	mass density of air, in kg/m^3 (Slug/ft^3)
C_s	=	shape coefficient (dimensionless)
A_{wind}	=	projected area of windage on a plane normal to the direction of the considered force, in m^2 (ft^2)
V_{wind}	=	1-minute mean wind speed at a given elevation above the SWL, in m/s (ft/s)

In the absence of experimental data, values in 5-3/3.5 TABLE 1 for the shape coefficient (C_s) are to be applied.

The conversion of mean wind speeds with different averaging time durations and the applicable wind profile are to follow 4-2/3.

For any direction of wind approaching to the structure, the wind force on flat surfaces is to be assumed to act normal to the surface. The wind force on cylindrical objects is to be assumed to act in the direction of the wind.

The area of open truss works commonly used for derricks and crane booms may be approximated by taking 30% of the projected area of both the windward and leeward sides with the shape coefficient taken in accordance with 5-3/3.5 TABLE 1.

Where one structural member shields another from direct exposure to the wind, shielding may be taken into account. Generally, the two structural components are to be separated by not more than seven times the width of the windward component in order for a reduction to be taken in the wind load on the leeward member.

Cyclic loads due to Vortex Induced Vibration of structural members are to be investigated, where applicable. Both drag and lift components of load due to vortex induced vibration are to be taken into account. The effects of wind loading on structural members or components that are not normally exposed to wind loads after installation are to be considered, especially during load-out or transportation operations.

TABLE 1
Shape Coefficients C_s

Shape	*Values of C_s*
Sphere	0.40
Cylindrical shape	0.50
Major flat surfaces and overall projected area of the Floating Support Structure	1.00
Isolated structural shapes (cranes, angles, beams, channels, etc.)	1.50
Under deck areas (smooth)	1.00
Under-deck areas (exposed beams and girders)	1.30
Derricks or truss cranes (each face)	1.25
Sides of buildings	1.50

5 Wave Loads *(1 July 2020)*

The wave forces acting on the Floating Offshore Wind Turbine consist of three primary components, [i.e., first order forces at wave frequencies, second order forces at frequencies lower than the wave frequencies and steady components of the second order forces (also known as mean drift forces)]. The mean and oscillatory low frequency drift forces may be determined by model tests or using hydrodynamic computer programs benchmarked against model test results or other data. For the TLP-type floating substructure, high-frequency wave loads also need to be considered as they may excite the floating substructure at its natural periods in heave, roll and pitch with typical natural periods ranging from 1 to 5 seconds.

For slender members that do not significantly alter the incident wave field, semi-empirical formulations, such as Morison's equation, may be used. For calculation of wave forces on structural configurations that significantly alter the incident wave field, appropriate methods which account for both the incident wave force (e.g., Froude-Krylov force) and the forces resulting from wave diffraction are to be used. In general, Morison's equation is applicable to slender members with diameters (or equivalent diameters giving the same cross-sectional areas parallel to the flow) less than 20 percent of the wave lengths.

For the floating substructure consisting of both large (columns and pontoons) members and slender members (bracing members), a combination of diffraction and Morison's equation can be used to calculate hydrodynamic characteristics and hydrodynamic loading. Alternatively, suitable model test results or full scale measurements can be used.

For installation sites where the ratio of water depth to wave length is less than 0.25, nonlinear effects of wave action are to be taken into account. This may be fulfilled by modifying linear diffraction theory to account for nonlinear effects or by performing model tests. Wave force calculations are to take into account shallow water effects which increase the current due to blockage effects, change the system natural frequency due to nonlinear behavior of moorings, and alter wave kinematics.

Wave slamming loads are to be considered for structural members such as pontoons, columns, braces, and members forming the underside of the topside deck structure that are subjected to wave slamming during transport and operation. Breaking wave slamming loads are also to be considered, if applicable. Guidance on the breaking wave hydrodynamics and the slamming loads exerted by a breaking wave on a cylindrical member is given in IEC 61400-3-1 (2019), Annex C. The ABS *FPI Rules* provides guidance on the calculation of local slamming pressure for scantling design. The effect of wave slamming loads, if relevant, is to be considered in the design of the stationkeeping system.

Green water effects are to be considered, as appropriate, for the strength of affected structures and for the stability analysis as described in Chapter 9.

7 Current Loads *(1 July 2020)*

Current induced loads on submerged hull, mooring or tendon lines, export electrical cables or any other submerged objects associated with the Floating Offshore Wind Turbine are to be determined based on analytical methods, model test data or full-scale measurements. When currents and waves are superimposed, the current velocity is to be added vectorially to the wave induced water particle velocity prior to computation of the total force. Current profiles used in the design are to be representative of the expected conditions at the installation site and determined in accordance with 4-4/1.

Current force, $F_{current}$, on the submerged part of any structure is calculated as the drag force by the following equation:

$$F_{current} = 1/2 \quad \rho_{water} C_D A_{current} \quad u_c |u_c|$$

where

$F_{current}$	=	current force, in N (lbf)
ρ_{water}	=	mass density of water, kg/m^3 (Slug/ft^3)
C_D	=	drag coefficient in steady flow (dimensionless)
$A_{current}$	=	projected area exposed to current, in m^2 (ft^2)
u_c	=	current velocity vector normal to the plane of projected area, in m/s (ft/s)

For long cylindrical members with large length-diameter ratios, lift force may become significant and is to be considered in the design.

Vortex Induced Vibration (VIV) is a resonant response caused by vortex shedding at resonant frequencies in current. Effects of VIV on fatigue and increased drag loads are to be assessed for structural members and for the stationkeeping system, where applicable. Dynamic amplification due to vortex shedding is to be considered if deemed necessary.

Vortex shedding may excite large resonant hull motions, particularly for a single column hull structure such as a Spar and a single column TLP, as well as a multicolumn hull structure with deep draft. These motions are commonly termed Vortex Induced Motions (VIM). Hull VIM, where applicable, and its effects on the strength and fatigue of the stationkeeping system and the export electrical cable are to be assessed.

9 Ice and Snow Accumulation Induced Loads *(1 July 2020)*

At locations where the Floating Offshore Wind Turbine is subjected to ice and snow accumulation, increased weight and change in effective area of structural members due to accumulated ice and snow are to be considered. Particular attention is to be paid to possible increases in aerodynamic and hydrodynamic loading due to the change in size and surface roughness of both non-rotating and rotating parts caused by ice and snow accumulation. Effect of ice and snow accumulation is also to be considered in the stability analysis if deemed necessary.

11 Earthquake Loads *(1 July 2020)*

For the Floating Offshore Wind Turbine supported by the tendon system and located in seismically active areas, the Strength Level and Ductility Level earthquake induced ground motions (see 4-6/9) are to be determined based on seismic data applicable to the installation site. Reference is made to API RP 2T for the guidance on designing the TLP-type Floating Offshore Wind Turbine for earthquake loading.

Earthquake ground motions are to be described by either applicable ground motion records or response spectra consistent with the return period appropriate to the design life of the Floating Offshore Wind Turbine . Available standardized spectra applicable to the region of the installation site are acceptable provided such spectra reflect site-specific conditions affecting frequency content, energy distribution, and duration. These conditions include:

- The type of active faults in the region
- The proximity of the site to the potential source faults
- The attenuation or amplification of ground motion between the faults and the site
- The soil conditions at the site

As appropriate, effects of soil liquefaction, shear failure of soft mud and loads due to acceleration of the hydrodynamic added mass by the earthquake, submarine slide, tsunamis and earthquake generated acoustic shock waves are to be taken into account.

13 Marine Growth

The following effects of anticipated marine growth are to be accounted for in the design.

- Increase in hydrodynamic diameter
- Increase in surface roughness used in the determination of hydrodynamic coefficients (e.g., lift, drag and inertia coefficients)
- Increase in permanent load and inertial mass

The amount of accumulation assumed for a design is to reflect the extent of and interval between cleaning of submerged structural parts.

15 Ice Loads *(1 July 2020)*

Ice loads acting on the Floating Offshore Wind Turbine may include both static and dynamic loads. Static loads can be generated by ice features lodged against the structure or by temperature fluctuations. Dynamic loads are normally caused by moving ice interactions with the Floating Support Structure and the stationkeeping system. The global forces exerted by ice on the Floating Offshore Wind Turbine as a whole and local concentrated load on structural elements are to be considered. The effects of rubble piles on the development of larger areas and their forces on the Floating Support Structure are to be considered. Further design considerations can be found in ISO 19906 and API RP 2N.

CHAPTER 6

Global Performance Analysis

CONTENTS

CHAPTER 6
Global Performance Analysis

SECTION 1
General Requirements

1 General *(1 July 2020)*

Global performance analyses are to determine the global effects of environmental conditions and other loads on the Floating Offshore Wind Turbine and its components including the tower, floating substructure, mooring lines or tendons, anchors, export electrical cable, etc. Global performance analyses are to be carried out for all critical conditions in the pre-service and in-service phases, represented by the design load conditions specified in Section 5-2.

Global performance analyses are intended to determine the following parameters:

i) Motions of the floating substructure in six degrees of freedom

ii) Mooring line (or tendon) and export electrical cable tensions, including the maximum and minimum tensions, and fatigue loads for the component design

iii) Tower base loads for the floating substructure analysis

iv) Tower top accelerations for the RNA design or selection

v) Critical global forces and moments, or equivalent design wave heights and periods as appropriate, for the hull structural analysis

vi) Hull hydrodynamic pressure loads for hull structural analysis

vii) Accelerations for the determination of inertia loads

viii) Air gap (also known as deck clearance or freeboard)

ix) Separation of resonance peaks, if required

Detailed guidance on global performance analyses for Floating Offshore Wind Turbines is provided in the ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbines*. Common practice in global performance analyses for floating offshore oil and gas production installations, as summarized in the ABS *FPI Rules* as well as applicable recognized standards such as those published by API and ISO, may be adapted for application to the Floating Offshore Wind Turbine, provided that the distinctive load and response characteristics of the Floating Offshore Wind Turbine are taken into account. The subjects that calling for special considerations include, but are not limited to, the following:

i) Metocean data that have a sufficient coverage on joint occurrence of wind, wave, current and water level conditions, with a special attention to wind conditions required by turbine load analyses *ii)* Dynamic interactions among the RNA, the tower, the floating substructure, the stationkeeping system and the power cable

iii) Actions of turbine's safety and control systems

iv) Time scale difference between wind speeds (normally 10 minutes or 1 hour) and storm waves (normally 3 hours)

v) Simulation time duration that is sufficient to capture statistics of responses

vi) Number of realizations (random seeds) that can achieve statistical convergence for the global responses of the Floating Offshore Wind Turbine subjected to turbulent wind and irregular wave loading simultaneously

3 Wave-induced Motion Responses *(1 July 2020)*

The wave-induced response of the Floating Offshore Wind Turbine normally consists of three categories of response, i.e., first order (wave frequency) motions, low frequency or slowly varying motions and steady drift. For the TLP-type floating substructure, high-frequency heave, roll and pitch motions could also be excited.

i) *First Order Motions.*These motions have six degrees of freedom (surge, sway, heave, roll, pitch and yaw) and are at wave frequencies. They can be obtained from model tests in regular or random waves or by numerical analysis in the frequency or time domain.

ii) *Low Frequency Motions.*These motions are induced by low frequency components of second order wave forces. The low frequency motions can be substantial, particularly at frequencies near the natural frequency of the Floating Offshore Wind Turbine. The low frequency motion-induced load in the mooring lines or tendons may act as a dominating design load for the stationkeeping system. The low frequency motions are to be calculated using appropriate motion analysis software or by model tests.

iii) *Steady (Mean) Drift.*The Floating Offshore Wind Turbine in waves experiences a steady drift along with the first and second order motions. The mean wave drift force and yawing moment are induced by the steady component of the second order wave forces. Mean drift forces and yawing moments are to be calculated using appropriate motion analysis programs or model tests.

iv) *High-frequency Responses.* High-frequency responses of the TLP-type floating substructure are significantly affected by various nonlinear excitation mechanisms. The relevant design guidance can be found in API RP 2T.

5 Critical Global Loads and Responses *(1 July 2020)*

Stochastic methods for global performance analyses of the Floating Offshore Wind Turbine provide a rational approach to calculate the global responses to irregular waves and turbulent winds. The results of global performance analyses are either in the format of response spectra in the frequency domain or the response time series in the time domain.

For the structural design, the complexity of the Floating Support Structure makes either the spectral-based or the time domain stress analyses a very challenging process. Furthermore, spectral-based stochastic stress analyses are not able to establish the correlation between external loads and internal forces/moments and stress distributions, making it difficult to optimize the structural design.

To address these issues and provide an engineering viable design method, the "design wave approach" is commonly adopted by the offshore oil and gas industry for the strength analysis of floating offshore structures. The merits of stochastic methods can be retained when the design waves are derived using the extreme stochastic values of pre-determined critical response parameters, which are compatible with a specific structural configuration. The procedures of development of the stochastic equivalent design wave cases for structural analysis are described in the ABS *MOU Rules* as well as API RP 2T.

7 Air Gap (Deck Clearance or Freeboard) *(1 July 2020)*

Unless topside deck structures, equipment on deck, and the tower, whenever relevant, are satisfactorily considered for direct passage of waves and wave impact, reasonable clearance between the wave crest and the structures for which wave forces are not considered in the design is to be established for all afloat modes of operation.

A minimum air gap of 1.5 m (5 ft) is to be provided between the 50-year return maximum wave crest elevation above the highest still water level (HSWL) (see 4-5/1) and the lowest edge of the floating substructure for which wave forces are not included in the design. Consideration is to be given to the effect of wave run-up and motions of the floating substructure. Local wave crest elevation is to be taken into account as appropriate. The requirement of air gap is to be checked for the design load case DLC 1.6, DLC 6.1, and DLC 6.2, as well as DLC 10.1, DLC 10.2 and DLC 10.3 specified in 5-2/3.

Under the survival load cases, as specified in 5-2/5, the air gap is not to be smaller than zero. The air gap criterion is also to be checked at various locations on the underside of topside deck. If the air gap criterion for the survival load cases is not satisfied, the anticipated local and global wave forces (including slamming) are to be suitably considered in the design of the stationkeeping system.

The air gap is normally determined by an appropriate model test. Alternatively, the air gap can also be calculated using a detailed global performance analysis that accounts for relative motions between the floating substructure and waves.

The following items are to be considered in the determination of the air gap:

i) Motions of the floating substructure in six degrees of freedom

ii) Restraints provided by the stationkeeping system

iii) Nonlinearity of wave profile

iv) Wave diffraction and run-up

v) Tide and water level effects, if applicable

vi) Various environmental headings

vii) Draft of the floating substructure

A general description of air gap analysis can be found in Section 7 of the ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbines*. Relevant guidance on air gap and wave impact analysis is provided in the ABS *Guidance Notes on Air Gap and Wave Impact Analysis for Semi-Submersibles*.

9 Model Testing *(1 July 2020)*

Model testing provides an independent check of system responses under simulated environmental conditions. It is also used for deriving some of the design parameters, such as the air gap and nonlinear effects, particularly for an innovative design. Model testing and numerical analyses are not to replace, but are rather to complement each other. The primary objectives of model testing are listed below:

- To determine the responses of a particular design, such as to calibrate low-frequency and high-frequency damping coefficients
- To verify analysis tools for prediction of system responses or to correlate the analysis results
- To derive some design information as a substitute for numerical analysis

Appropriate environmental conditions are to be selected in the model testing. Due consideration is to be given to the model scaling for the Floating Offshore Wind Turbine where both hydrodynamic and aerodynamic load effects need to be taken into account.

Additional guidance on hydrodynamic model tests for floating offshore structures can be found in API RP 2T and ISO 19904-1.

CHAPTER 6
Global Performance Analysis

SECTION 2
Analysis Methodologies

1 General *(1 July 2020)*

Because significant interactions could occur among the turbine RNA, the tower, the floating substructure, the stationkeeping system and, if relevant, the power cable, an integrated model (also termed "a coupled model") including these components is recommended to be used for global performance analyses. An alternative method, where the dynamic analyses of the stationkeeping system or the export electrical cable are performed separately by using the motions of the floating substructure as boundary conditions, may also be acceptable, provided the coupling effects are adequately taken into account. See the ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbines* for further guidance.

It is to be demonstrated that the global performance analysis software used in the design has the capability of appropriately considering interactions among aerodynamic loads, hydrodynamic loads, actions of turbine safety and control systems and structural dynamic responses of the Floating Offshore Wind Turbine. The analysis procedure is to be developed with consideration of the application limit of the selected software. Both industry-recognized software and in-house software may be used for the analyses. However, in-house software is to be adequately validated against model tests or industry-recognized software.

3 Frequency Domain Analyses *(1 July 2020)*

Frequency domain analyses solve the equations of motion using methods of harmonic analysis or methods of Laplace and Fourier transformations.

In order to evaluate the wave-frequency responses of the Floating Offshore Wind Turbine , linear wave theory is usually employed in the wave frequency analysis. Alternative methods may be applied to evaluate the effects of finite amplitude waves. The low frequency motion analysis is to be carried out to evaluate the effects caused by wind dynamics and wave drift forces. The damping levels used in the analyses are to be properly determined and documented. For the TLP-type floating substructure, where second-order sum-frequency effects are determined to be significant, the high frequency springing responses of the floating substructure and tendons are to be evaluated.

Frequency domain analyses for aerodynamic responses of turbine RNA and effects of turbine control systems are to be properly formulated. Preferably, combined aerodynamic, hydrodynamic and control system actions in the frequency domain are used in the calculation of the dynamic responses of the Floating Offshore Wind Turbine.

Frequency-domain analyses, by nature, cannot capture nonlinear dynamic interactions among the components of the Floating Offshore Wind Turbine. They are also unable to take into account transient responses as well as nonlinear aerodynamic and hydrodynamic load effects. Because of these limitations, most of the currently available simulation software for floating offshore wind turbines is based on the time domain analysis approach as described in 6-2/5. Frequency domain analyses are normally performed to calculate the hydrodynamic coefficients which are used as input to time domain analyses.

5 Time Domain Analyses *(1 July 2020)*

The time domain analysis procedure consists of a numerical solution of the equations of motion for the Floating Offshore Wind Turbine subjected to external forces exerted by environmental conditions and the operation of the wind turbine. Time series of wind and wave conditions are generated for simulating turbulent wind conditions and stochastic wave elevations and kinematics.

Time domain analyses are the preferable approach for global performance analysis of the Floating Offshore Wind Turbine, primarily because they can provide a rational means of modeling the nonlinear and transient effects in global responses of a floating offshore wind turbine. These nonlinear effects include hydrodynamic drag forces, finite wave amplitude effects, nonlinear restoring forces from moorings, and effects of motion suppression devices or components (e.g., heave plates). When an integrated (coupled) model is used for global performance analyses, coupling effects among responses of the turbine RNA, the tower, the floating substructure, the stationkeeping system and the export electrical cable can be taken into account at each incremental analysis time step. A more realistic simulation of the effects of a turbine control system and turbine's operating conditions can also be achieved using this approach.

In time domain analyses, the most probable maximum responses are to be predicted using appropriate distribution curves fitted to the simulation results or other recognized statistical techniques. Time domain analyses are to be carried out for a sufficiently long time to achieve stationary statistics, particularly for low frequency responses. Multiple realizations of the same conditions may be necessary to generate adequate data for statistical analysis and to verify consistency of the simulation. The designer is to demonstrate the adequacy of the selected simulation time duration and the number of realizations.

For the TLP-type floating substructure, the ringing (the high frequency vertical vibration excited by impulsive loading) and springing (the high frequency vertical vibration excited by cyclic loading at or near the resonant periods) responses of the floating substructure and the tendon are to be considered as appropriate. Further guidance on high frequency ringing and spring analyses can be found in API RP 2T.

The effect of Vortex Induced Motions (VIM, see 5-3/5) for the floating substructure having Spar or single column TLP floating substructures or other deep-draft floating substructures are to be taken into account as appropriate.

CHAPTER 7

Design of Floating Substructures

CONTENTS

CHAPTER 7
Design of Floating Substructures

SECTION 1
General Requirements

1 Overview *(1 July 2020)*

This Section provides general requirements to be applied in the design of the Floating Support Structure. The criteria in Sections 7-2 and 7-3 dealing specifically with the steel and concrete structural design are to be applied along with the requirements specified in this Section.

Design documentation of structures to be submitted for review is specified in 1-1/11. General design considerations for the structures are provided in Section 3-1.

The design criteria in Chapter 7 are to be applied to the design of the floating substructure. Compliance of the tower design with the requirements in this Chapter may be required (see 3-1/1).

3 Format of Design Approach *(1 July 2020)*

The Floating Support Structure can be considered as having two parts. The first is the floating substructure, which in this Guide can be one of four types (i.e. Column-Stabilized, TLP, Spar-type, or Barge as defined in 1-1/17.1.1 through 1-1/17.1.4). There may also be a topside structure atop the hull. If the topside structure is integrated with the hull, the hull and the topside structure are considered together. If the topside is non-integral with the hull, it can be designed independent of the hull although any significant interaction between the hull and the topside is to be suitably considered. The second part of the Floating Support Structure is the tower. The topside structure atop the hull, the hull interface structure to the power cable, and structural components supporting the tower on the hull are considered part of the floating substructure in this Guide.

The design requirements for the steel hull and its steel topside structure are given in 7-2/7.3, which is based on the Working Stress Design (WSD) formatted criteria, or 7-2/7.5, which provides the Load and Resistance Factor Design (LRFD) formatted criteria.

The design requirements for the concrete components of the floating substructure are specified in Section 7-3, which is based on the LRFD formatted criteria.

In addition to the design approaches outlined in this Guide, suitable considerations are to be given to the serviceability of the structure relative to excessive deflection, vibration and, in the case of concrete, cracking.

5 Design Load Conditions *(1 July 2020)*

Load combinations are to reflect the design load conditions as specified in Chapter 5.

With reference to Chapter 5, suitable stochastic methods are to be used to establish design loads. The influence of the less severe environmental loads in combination with the turbine operational loads is to be investigated for their potential to produce maximum peak load effects in the Floating Support Structure.

Dynamic analyses are to be performed to assess effects of environmental or other types of loads. When a fatigue analysis is performed, a long-term distribution of stress range, with proper consideration of dynamic effects, is to be determined for relevant loadings anticipated during the pre-service and in-service phases of the Floating Offshore Wind Turbine.

7 Design Life *(1 July 2020)*

The design life of the Floating Support Structure, which constitutes part of the Floating Offshore Wind Turbine, is to be in accordance with 3-1/5.

9 Long-Term and Secondary Effects

Consideration is to be given to the following effects, as appropriate to the planned Floating Support Structure:

i) Local vibration due to machinery, equipment and vortex shedding

ii) Stress concentrations at critical joints

iii) Secondary stresses induced by large deflection

iv) Cumulative fatigue

v) Corrosion

vi) Abrasion due to ice

vii) Freeze-thaw action on coatings and the concrete

11 Zones of Exposure *(1 July 2020)*

Measures taken to mitigate the effects of corrosion are to be specified and described by the following definitions for corrosion protection zones.

i) *Submerged Zone.*That part of the Floating Support Structure below the Splash Zone.

ii) *Splash Zone.*That part of the Floating Support Structure as defined in 1-1/17.3.27. Characteristically, the Splash Zone is not easily accessible for field painting, nor protected by cathodic protection.

iii) *Atmospheric Zone.* That part of the Floating Support Structure above the Splash Zone.

Additionally, for the Floating Offshore Wind Turbine located in areas subjected to floating or submerged ice, the portion of the Floating Support Structure expected to come into contact with floating or submerged ice is to be designed with consideration for such contact.

CHAPTER 7
Design of Floating Substructures

SECTION 2
Steel Structures

1 General

1.1 Materials

The requirements of this Section are specified for structures constructed of steel, which is manufactured and has properties in accordance with Chapter 2 and 3-1/19. Where it is intended to use steel or other materials having properties differing from those of Chapter 2, their applicability will be considered by ABS upon reviewing the specifications of alternative materials and the proposed methods of fabrication.

1.3 Corrosion Protection *(1 July 2020)*

Materials are to be protected from corrosion using a corrosion protection system such as coatings. The system is to be effective from the time the floating substructure is initially placed on site. Where the sea environment contains unusual contaminants, any special corrosive effects of such contaminants are to be considered. For the design of protection systems, reference is to be made to the publications from NACE International: SP0176 and SP0108, or other recognized standards.

1.5 Access for Inspection *(1 July 2020)*

In the design of the floating substructure, consideration is to be given to providing access for inspectionduring construction and, to the extent practicable, for survey after construction. Any openings on the floating substructure for the purpose of providing access to the structure are to be evaluated to verify there is no adverse effect on the integrity and buoyancy of the structure.

3 Scantling Design of the Hull Structures

The initial scantling design of hull structural members, including plating, stiffeners, girders, brackets, etc., is to be in accordance with Part 5B of the *FPI Rules*. The aspects that are not covered by the *FPI Rules* are to be based on recognized standards. The obtained initial scantlings are to be considered as minimum values. The application of the design criteria specified in the remainder of this Section cannot be used to justify reductions in these scantlings. However, the scantlings are to be suitably increased where required by the criteria specified in the remainder of this Section.

Pontoons, columns, tanks and bracing members may be considered either as framed or unframed shells. Ring girders, bulkheads, or other suitable diaphragms are to be adequate to maintain shape and stiffness under all anticipated loadings in association with established analysis methods.

5 Structural Strength and Fatigue Analysis *(1 July 2020)*

The steel structure of the floating substructure is to be designed and analyzed for the loads to which it is likely to be exposed during the pre-service and in-service phases. Loads to be investigated are to include at least those relating to both realistic operating and environmental conditions combined with permanent and variable loads (see Chapter 5, Section 1) that are appropriate to the functions and operations of the Floating Offshore Wind Turbine.

Loading conditions are to be in accordance with 7-1/5 for the strength and fatigue analysis of the floating substructure.

The general guidance on choosing appropriate approaches to perform structural analyses for the floating substructure is provided in Part 5B of the *FPI Rules*. The designer is to verify that the adopted structural analysis method is suitable for specific structural behaviors and can lead to accurate analysis results.

Structural responses obtained from the structural analysis are to be checked against the design criteria specified in 7-2/7 for the strength (yielding and buckling) assessment or 7-2/9 for the fatigue assessment.

7 Strength Design Criteria

7.1 General

The strength design criteria specified in this Subsection are to be applied to those design load cases relevant to the strength assessment. A minimum set of Design Load Cases (DLCs) for strength assessment is defined in 5-2/3.5 TABLE 1, where the 'Type of Analysis' column is denoted 'S'.

7.3 Working Stress Design (WSD) Approach *(1 July 2020)*

When the strength design of the floating substructure is based on the WSD approach, the design acceptance criteria are expressed in terms of appropriate allowable stresses. Linear, elastic methods can be employed in structural analyses provided proper measures are taken to prevent general and local buckling failure. The loading conditions for the strength analysis are to be in accordance with 7-2/5. A factor of 1.0 applies to all categories of load. When a variable load is considered a favorable load that relieves total load responses, the minimum value of this variable load is to be used in the load combination.

The safety factors specified in this Subsection are to be applied in conjunction with the normal (N) and abnormal (A) design conditions as well as the temporary design conditions (T) for load-out, transportation, installation, maintenance and repair of the Floating Offshore Wind Turbine, as defined in 5-2/3.3 and 5-2/3.5 TABLE 1.

7.3.1 Individual Stresses in Structural Members

Individual stress components or direct combinations of such stresses in a structural member are not to exceed the allowable stress as obtained from the following equation:

$$F_{allowable} = F_y / C_{SF}$$

where

$F_{allowable}$	=	allowable stress
F_y	=	specified minimum yield strength, as defined in the ABS *Rules for Materials and Welding (Part 2)*
C_{SF}	=	safety factor

- For the normal design conditions (designated 'N'in the column entitled ' Safety Factor' in 5-2/3.5 TABLE 1)

= 1.5 for axial or bending stress

= 2.5 for shear stress

- For the abnormal design conditions (designated 'A' in the column entitled 'Safety Factor' in 5-2/3.5 TABLE 1)

  = 1.25 for axial or bending stress

  = 2.0 for shear stress

- For the temporary design conditions (designated 'T' in the column entitled 'Safety Factor' in 5-2/3.5 TABLE 1)

  = 1.67 for axial or bending stress

  = 2.75 for shear stress

7.3.2 Buckling Strength of Structural Members Subjected to a Single Action

Buckling is to be considered for a structural element subjected to compressive axial load or bending moment. The computed compressive or bending stress is not to exceed the allowable stress as obtained from the following equation:

$$F_{allowable} = F_{cr}/C_{SF}$$

where

$F_{allowable}$ = allowable stress

F_{cr} = critical buckling strength of a structural member subjected to axial compression or critical bending strength of a structural member subjected to bending moment, as defined in Section 2 of the ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures*

C_{SF} = safety factor

- For the normal design conditions (designated 'N' in the column entitled 'Safety Factor' in 5-2/Table 1)

  = $1.5/\Psi$

- For the abnormal design conditions (designated 'A' in the column entitled 'Safety Factor' in 5-2/Table 1)

  = $1.25/\Psi$

- For the temporary design conditions (designated 'T' in the column entitled 'Safety Factor' in 5-2/Table 1)

  = $1.67/\Psi$

ψ = adjustment factor, as defined in 1/11 of the ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures*

7.3.3 Structural Members Subjected to Combined Axial Load and Bending

Structural members subjected to axial tension or compression in combination with bending are to be designed according to Section 2 of the ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures* in conjunction with the utilization factors, which are the reciprocals of the corresponding safety factors specified in 7-2/7.3.2.

7.3.4 Allowable Stress of Plated Structures

For plated structures where the equivalent stress is determined using the von Mises equivalent stress criterion, the equivalent stress is not to exceed the allowable stress as obtained from the following equation:

$$F_{allowable} = F_y / C_{SF}$$

where

$F_{allowable}$ = allowable stress

F_y = specified minimum yield strength, as defined in the ABS *Rules for Materials and Welding (Part 2)*

C_{SF} = safety factor

- For the normal design conditions (designated 'N' in the column entitled 'Safety Factor' in 5-2/3.5 TABLE 1)

  = 1.33

- For the abnormal design conditions (designated 'A' in the column entitled 'Safety Factor' in 5-2/3.5 TABLE 1)

  = 1.11

- For the temporary design conditions (designated 'T' in the column entitled 'Safety Factor' in 5-2/3.5 TABLE 1)

  = 1.5

7.3.5 Buckling Strength of Plated Structures

The buckling strength of plated structures is to be designed according to the ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures* in conjunction with the utilization factors, which are the reciprocals of the corresponding safety factors specified in 7-2/7.3.2.

7.5 Load and Resistance Factor Design (LRFD) Approach *(1 July 2020)*

In lieu of the WSD approach described in 7-2/7.3, the design of steel structures can also be based on the LRFD approach.

The loading conditions for the strength analysis are to be in accordance with 7-1/5. The partial safety factors (γ_f) for loads, as specified in 7-2/7.5 TABLE 1, are to be applied to the environmental loads.

A partial safety factor of 1.0 is to be applied to permanent loads and variable loads, where they are combined with the design environmental loads. However, where a permanent load or a variable load is considered as a favorable load that relieves total load responses, a partial safety factor of 0.9 is to be applied to this load. Where a variable load is considered a favorable load, the minimum value of this variable load is to be used in the load combination.

TABLE 1
Partial Safety Factors (γ_f) for Environmental Loads

Normal (N)	*Abnormal (A)*	*Temporary (T)*
1.35	1.1	1.5

Note: The design conditions represented by 'N', 'A' and 'T' are defined in 5-2/3.3 and 5-2/3.5 TABLE 1.

Alternatively, the partial load factors specified in IEC 61400-3-2 (2019) can be applied to the load effects determined by the dynamic analysis of the floating offshore wind turbine using unfactored loads.

The resistance factors are to be determined in accordance with ISO 19904-1 and the strength capacities are to be determined in accordance with the ABS *Guide for Load and Resistance Factor Design (LRFD) Criteria for Offshore Structures* or equivalent. Where the resistance concerns bolted connections and fillet and partial penetration welds, the minimum resistance factor of 1.30 is to be applied.

9 Fatigue Assessment *(1 July 2020)*

The fatigue assessment is to be performed to verify adequate capacity against fatigue failure within the design life of the Floating Offshore Wind Turbine.

The fatigue assessment is to be performed for structural members and connections where fatigue is a probable mode of failure, or for which experience is insufficient to justify safety from possible cumulative fatigue damage. Emphasis is to be given to structural members and connections that are difficult to inspect and repair once the Floating Offshore Wind Turbine is in service and to those areas susceptible to corrosion-accelerated fatigue. Guidance on the fatigue analysis of the floating substructures is provided in Appendix 3.

For structural members and connections that require a detailed assessment of cumulative fatigue damage, the calculated fatigue life is not to be less than the design life of the Floating Offshore Wind Turbine times the safety factors for fatigue life (i.e., fatigue design factors (FDFs), as listed in 7-2/9 TABLE 2).

The fatigue resistance of structural details is to be evaluated in accordance with the ABS *Guide for Fatigue Assessment of Offshore Structures*. Suitable S-N curves are to be selected, with special attention being given to the application and limitations of those curves.

The loading conditions for the fatigue assessment are to be in accordance with 7-2/5. A minimum set of Design Load Cases (DLCs) for fatigue assessment is specified in 5-2/3.5 TABLE 1, where ‘F’ in the column titled ‘Type of Analysis’ designates the fatigue assessment. Loading history of the floating substructure during pre-service and in-service phases is to be accounted for. Fatigue analyses are to be carried out using an appropriate loading spectrum or time series in accordance with the accepted theories in calculating accumulated damage.

In the case that the design is based on the LRFD approach, the load factors for all load categories are to be taken as 1.0 in the fatigue assessment.

TABLE 2
Safety Factors for Fatigue Life of Structures (Fatigue Design Factors [FDF]) *(1 July 2020)*

Importance	*Inspectable and Repairable*	
	Yes	*No*
Non-Critical	2	3
Critical	3	5

Notes:

1 ‘Critical’ indicates that failure of these structural items would result in the rapid loss of structural integrity and produce an event of unacceptable consequence.

2 FDF = 1.0 may be applicable to Inspectable and repairable non-critical structural members above the splash zone

3 For critical structures of the topside structure that is non-integral with the hull structure and the turbine tower above the splash zone, FDF = 2.0 may be applied, provided these structures can be inspected during the periodical survey or when structural damage is suspected such that critical crack development can be detected and repaired.

11 Analysis and Design of Structures

11.1 Primary Structures

11.1.1 General *(1 July 2020)*

Structural analyses are to be performed to assess yielding, buckling and fatigue of the hull, the integrated topside deck structure, the turbine tower if classed, and main intersections of hull primary structural components to the topside deck structure and the turbine tower. The analyses are to verify the adequacy of scantlings established in the basic design as described in 7-2/3, but they are not to be used to reduce these scantlings. Reference is made to the *FPI Rules* for general procedures and methodologies of structural analysis and design for the floating substructure.

11.1.2 Global Strength Analysis *(1 July 2020)*

The primary structural components of the hull, integrated topside deck structure and turbine tower if classed are to be analyzed using the design load conditions specified in 7-1/5. The analyses are to be performed using recognized calculation methods which are to be fully documented and referenced.

The global strength of the floating substructure is to be designed to resist maximum global effects induced by the critical global loads/responses described in 6-1/5. The type of critical global loads/responses depends on the specific configuration of the floating substructure.

11.1.3 Major Joint Analysis – Analysis for Main Intersections of Primary Structures *(1 July 2020)*

When details of main intersections are not adequately captured in a global strength model, local FEM analyses are to be used to design these areas.

For the Column-Stabilized or TLP-type floating substructure, the main intersections include connections of pontoon to pontoon, column to pontoon, column to topside deck structure, and the tower to hull structure. For twin-pontoon Column-Stabilized floating substructures, special attention is to be given to brace connections to braces, columns, pontoons, and topside deck structure.

For the Spar-type floating substructure with truss connections, the main intersections include connections of top section to topside deck structure, truss to hull structure, and the tower to hull structure. Connections of tubular structural members are to be designed to provide effective load transmission between joined members, to minimize stress concentration, and to prevent excessive punching shear. Connection details are also to be designed to minimize undue constraints against overall ductile behavior and to minimize the effects of post-weld shrinkage. Undue concentration of welding is to be avoided.

For Barge-type floating substructures, the main intersections include connections of the ring pontoon and the tower to hull structure.

For all types of floating substructure, when the tower and its connections to the RNA and/or the floating substructure are within the scope of classification, the interface structures of the tower to the RNA and/or the floating substructure are to be considered in the analysis.

Structural analyses are to be performed to assess yielding, buckling, and fatigue of the tower pedestal and foundation (hull structure supporting the pedestal) subjected to static and dynamic loads. Dynamic response of the tower is to be determined in accordance with the requirements of Chapter 6 for global performance analyses and with consideration of the Design Load Cases specified in 5-2/3.3 for the floating substructure.

11.1.4 Fatigue Assessment *(1 July 2020)*

Fatigue assessment of the primary structures mentioned in 7-2/11.1.1 is to follow 7-2/9. Special attention is to be given to the major joints mentioned in 7-2/11.1.3. Attention is also to be given to the designs of structural notches, cutouts, brackets, toes, and abrupt changes of structural sections where they are prone to fatigue damages.

11.1.5 Non-Integrated Deck *(1 July 2020)*

The design of non-integrated decks is to adhere to 5B-1-2/5.3 and 5B-2-3/5.3 of the *FPI Rules*.

11.3 Other Major Structures

11.3.1 General *(1 July 2020)*

Depending on specific features of the floating substructure, additional analyses may be required to verify the design of other structural components, such as

i) Hull structural interface with the stationkeeping system (fairlead, chain stopper, and winch foundations)

ii) Hull structural interface with the power cable system (I-tube and J-tube support structure and foundation)

iii) Equipment/machinery support structures and their interface to the topside deck structure or the hull structure

iv) Topside deck structural interface with deck modules, if relevant

11.3.2 Structural Interface with Equipment/Machinery Foundations or Deck Modules *(1 July 2020)*

The topside deck structure or the hull structure may require reinforcements to resist reaction forces from foundations of equipment/machinery, such as crane, power cable, and deck modules. The reinforcements of the topside deck structure or the hull structure are referred to as backup structures. The forces to be resisted by the backup structures are to be designed for maximum anticipated gravity, functional, and environmental loads together with inertia loads induced by motions of the floating substructure and verified against the design criteria and requirements specified in 7-2/7. If deemed necessary, the fatigue strength is to meet the requirements of 7-2/9.

11.3.3 Hull Structural Interface with the Stationkeeping System *(1 July 2020)*

Each individual foundation and backup structure of the fairlead, chain jack, winch or tendon porch is to be designed for the breaking strength of the mooring line or tendon with a safety factor of 1.25.

The foundation and backup structure for multiple fairleads, chain jacks, winches or tendon porches are to be designed for the maximum anticipated mooring or tendon loads and verified against the design criteria and requirements specified in 7-2/7.3.

The fatigue life is to satisfy the requirements in 7-2/9 with consideration of the effects of both local drag and inertia loads on the mooring lines or tendons and the global motions of the floating substructure.

11.3.4 Hull Structural Interface with the Power Cable System *(1 July 2020)*

I-tube and J-tube support structure and foundation for the power cable system are to be designed for the maximum anticipated static and dynamic cable loads based on cable dynamic analysis and verified against the design criteria and requirements specified in 7-2/7.3 or 7-2/7.5.

The fatigue life is to satisfy the requirements in 7-2/9 with consideration of the effects of both local drag and inertia loads on I-tube and J-tube support structure, dynamic cable loads, and the global motions of the floating substructure.

11.3.5 Helicopter Deck

The design of the helicopter deck is to comply with the requirements of 3-2-2/3 of the *MOU Rules*.

11.5 Local Structures *(1 July 2020)*

Structures that do not directly contribute to the overall strength of the floating substructure (i.e., their loss or damage does not impair the structural integrity of the floating substructure) are considered to be local structures.

Local structures are to be adequate for the nature and magnitude of applied loads. The criteria specified in 7-2/7 are in general applicable to the design of local structural components, except for those structural parts whose primary function is to absorb energy, in which case sufficient ductility is to be demonstrated.

11.7 Guards and Rails *(1 July 2020)*

Guards and rails are to comply with the requirements of 5-3-1/5 of the *MOU Rules*, for application to the perimeters of the floating substructure. Alternative arrangements, such as a minimum 1.07 m (42 in.) high and two-tier evenly spaced handrail with a kickboard, may be considered by ABS, provided they are also acceptable to the coastal State or other governmental authorities having jurisdiction.

11.9 Vortex Shedding Strakes

Vortex shedding strakes may be installed to reduce the VIM effects on the deep-draft hull. Yield, buckling and fatigue strengths of vortex shedding strakes are to be checked with consideration of the effects of local drag and inertia loads as well as the effects of global motions of the hull.

11.11 Appurtenances *(1 July 2020)*

Main appurtenances attached to the exterior of the hull are to be evaluated with consideration of the effects of local drag and inertia loads together with any appropriate consideration of global action of the floating substructure. The backup structures are also to be designed for the same loads and safety factors, as a minimum.

11.13 Temporary Structures

Structures built for temporary use in the pre-service conditions are not subject to ABS review. However, the arrangements and details of these structures are to be submitted for reference in order to verify the adequacy of the local and global strength of the hull and topside deck to support these temporary structures during operation in the pre-service condition. The backup structures are to be designed for the safety factors outlined in 7-2/7 for temporary design conditions.

11.15 Protection of Deck Openings

All openings on the deck are to comply with Section 3-2-15 of the *Marine Vessel Rules*.

13 Structural Connections *(1 July 2020)*

Structure connections are to be accomplished by positive, controlled means such as welding, grouting, or other mechanical connectors. Such attachments are to be capable of withstanding the anticipated static and long-term cyclic loadings. Details of mechanical connectors are to be submitted for review.

The welding of steel for the floating substructure and the design of welded connections are to follow the requirements of Chapter 2. Requirements for the connection of welded tubular members are described in 7-2/11.1.3.

In the design of grouted connections, consideration is to be given to the use of mechanical shear connectors as their presence increases the strength of the connection and alleviates the effect of long-term grout shrinkage. Adequate clearance in the annulus between an inner and an outer member is to be provided for proper placement of the grout. Reliable means for the introduction of the grout to the annulus are to be provided in order to achieve complete filling of the annulus and to minimize the possibility of dilution of the grout and the creation of voids in the grout.

Particulars of grouting mixtures used in the grouted connections are to be submitted for review. For grout material, reference can be made to 2-1/3.21 of the ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbines*.

For grouted connections subjected to axial loads, general references are to be made to API RP 2A. Special attention is to be paid to the limitation of geometric configuration required by the design criteria in API RP 2A. For grouted connections whose geometries are not covered by the existing design criteria, special consideration is to be given to the effects of reduced confinement on allowable bond stress, and suitable analyses or tests are to be submitted for review.

For those grouted connections expected to resist bending moments, their strength is to be assessed by suitable analysis methods or by tests. The assessment results are to be submitted for review.

For bolted flange connections, special care is to be taken to verify evenness of contact surface to avoid overstressing of bolts. The design and installation are to be in accordance with recognized standards such as the AISC *Steel Construction Manual*. Consideration is to be given to friction factors, relaxation, stress corrosion cracking, bolt fatigue, brittle failure, and other factors or combinations that may be present.

CHAPTER 7
Design of Floating Substructures

SECTION 3
Concrete Structures

1 General (1 July 2020)

The requirements of this Section are to be applied to the floating substructure constructed of reinforced and prestressed concrete.

1.1 Materials (1 July 2020)

Unless otherwise specified, the requirements of this Section are intended for the floating substructure constructed of materials manufactured and having properties as specified in Section 2-1. Use of materials having properties differing from those specified in Section 2-1 will be specially considered by ABS. Specifications for alternative materials, details of the proposed methods of manufacture and, where available, evidence of satisfactory previous performance, are to be submitted for review.

For structural lightweight concrete, the reference is made to ACI 213R, and lightweight aggregates are to conform to the requirements of ASTM C330.

1.3 Durability (1 July 2020)

Materials, concrete mix proportions, construction procedures and quality control are to be chosen to produce satisfactory durability for structures located in a marine environment. Issues to be specifically addressed include chemical deterioration of concrete, corrosion of the reinforcement and hardware, abrasion of concrete, freeze-thaw durability, and fire hazards as they pertain to the zones of exposure defined in 7-1/11.

Test mixes are to be prepared and tested early in the design phase to verify that proper values of strength, creep, alkali resistance, etc. can be achieved.

1.5 Access for Inspection (1 July 2020)

The components of the structure are to be designed to enable their inspection during construction and, to the extent practicable, periodic survey after installation.

3 Design Method (1 July 2020)

The criteria specified in this Section for concrete structures are based on the Load and Resistance Factor Design (LRFD) approach.

3.1 Load Magnitude

The magnitude of a design load for a given type of loading k is obtained by multiplying the load, F_k, by the appropriate load factor, c_k (i.e., design load = $c_k F_k$).

3.3 Design Strength

In the analysis of sections, the design strength of a given material is obtained by multiplying the material strength, f_k, by the appropriate strength reduction factor, φ (i.e., design strength = φf_k).The material strength, f_k, for concrete is the specified compression strength of concrete (f'_c) after 28 days and for steel is the minimum specified yield strength (f_y). See also 7-3/7.3.

3.5 Design Reference

Design considerations for concrete floating substructure not directly addressed in this Guide are to follow the requirements of the ACI 318 and ACI 357, or equivalent.

5 Design Requirements *(1 July 2020)*

5.1 General

The strength of the concrete floating substructure of a Floating Offshore Wind Turbine is to be such that adequate safety exists against failure of the structure or its components. Among the modes of possible failure to be considered are the following:

i) Loss of overall equilibrium

ii) Failure of critical section

iii) Instability resulting from large deformation

iv) Excessive plastic or creep deformation

The serviceability of the floating substructure is to be assessed. The following items are to be considered in relation to their potential influences on the serviceability of the structure.

i) Cracking and spalling

ii) Deformation

iii) Corrosion of reinforcement or deterioration of concrete

iv) Vibration

v) Leakage

5.3 Load Combinations

Loads that produce the most unfavorable effects on the concrete structure during the pre-service and in-service phases are to be considered. Loads to be investigated are to include at least those relating to both realistic operating and environmental conditions combined with permanent and variable loads, as defined in Section 5-1, that are appropriate to the functions and operations of the Floating Offshore Wind Turbine.

Load combinations are to reflect the design load conditions as specified in Section 5-2 for the strength and fatigue analysis of the floating substructure. The load combination is to be in accordance with 7-2/7.5 in general. The load categories referred in this Section (i.e., permanent loads, variable loads and environmental loads) are defined in 5-1/3.

The partial safety factors for loads are defined in 7-2/7.5.

The Design Load Cases (DLCs) in 5-2/3.3 are to be assessed as a minimum requirement of design load conditions. DLCs for ice conditions are to be considered in accordance with 5-2/3 for the installation site where ice is expected to occur.

5.5 Strength Reduction Factors

The strength of a member or a cross section is to be calculated in accordance with 7-3/7 and it is to be multiplied by the following strength reduction factor, φ.

i) In the case of bending without axial tension, φ = 0.90

ii) In the case of axial compression or axial compression combined with bending:

- For reinforced members with spiral reinforcement, φ = 0.70
- For other reinforced members (excluding slabs and shells), φ = 0.65

  The values given in the above for two types of members may be increased linearly to 0.9 as φP_u decreases from $0.1 f'_c A_g$ or φP_b, whichever is smaller, to zero, where

  f'_c = specified compression strength of concrete

  A_g = gross area of section

  P_u = axial design load in compression member

  P_b = axial load capacity assuming simultaneous occurrence of the ultimate strain of concrete and yielding of tension steel

- For slabs and shells, φ = 0.70

iii) In the case of shear and torsion, φ = 0.75

iv) In the case of bearing on concrete, φ = 0.65, except for post-tensioning anchorage bearing. For bearing on concrete in post-tension anchorage, φ = 0.85.

Alternatively, the expected strength of concrete members can be determined by using idealized stress-strain curves and material factors (c_M) given in ACI 357R. The material factors applied to the stress-strain curves limit the maximum stress to achieve the desired reliability similar to using the strength reduction factors given above. The strength reduction factors (φ) and the material factors (c_M) are not to be used simultaneously.

5.7 Fatigue

The fatigue strength of the concrete floating substructure of an offshore wind turbine is considered satisfactory if under the unfactored fatigue loads (i.e., c_k = 1) the following conditions are satisfied. The fatigue analysis is based on the stress in a critical section. The stress range is the stress range derived from all fatigue load cycles with a 1-year return probability level.

i) The stress range in reinforcing or prestressing steel does not exceed 138 MPa (20 ksi), or where reinforcement is bent, welded or spliced, 69 MPa (10 ksi).

ii) There is no membrane tensile stress in concrete and not more than 1.4 MPa (200 psi) flexural tensile stress in concrete.

iii) The stress range in compression in concrete does not exceed $0.5 f'_c$ where f'_c is the specified compressive strength of concrete.

iv) Where maximum shear exceeds the allowable shear of the concrete alone, and where the cyclic range is more than half the maximum allowable shear in the concrete alone, all shear is taken by reinforcement. In determining the allowable shear of the concrete alone, the influence of permanent compressive stress may be taken into account.

v) In situations where fatigue stress ranges allow greater latitude than those under the serviceability requirements given in 7-3/Table 1, the latter condition is to assume precedence.

vi) Bond stress does not exceed 50% of that permitted for static loads. If lap splices of reinforcement or pretensioning anchorage development are subjected to cyclic tensile stresses greater than 50% of the allowable static stress, the lap length or prestressing development length is to be increased by 50%.

Where the above nominal values are exceeded, an in-depth fatigue analysis is to be performed. In such an analysis, the possible reduction of material strength is to be taken into account on the basis of appropriate data (S-N curves) corresponding to the 95th percentile of specimen survival. In this regard, consideration is to be given not only to the effects of fatigue induced by normal stresses, but also to fatigue effects due to shear and bond stresses under unfactored load combinations.

Particular attention is to be given to submerged areas subjected to the low-cycle, high-stress components of the loading history.

In prestressed members containing unbonded reinforcement, special attention is to be given to the possibility of fatigue in the anchorages or couplers that may be subjected to corrosive action.

Fatigue analyses are to be carried out using an appropriate loading spectrum or time series in accordance with the accepted theories in calculating accumulated damage. The fatigue design factors (FDFs) are defined in 7-2/Table 2, except that the calculated fatigue life is to be at least twice the design life of the Floating Offshore Wind Turbine.

5.9 Serviceability Requirements

5.9.1 Serviceability

The serviceability of the concrete floating substructure is to be checked by the use of stress-strain diagrams, as depicted in 7-3/Figure 1 and 7-3/Figure 2. The strength reduction factor, φ, and partial safety factors for loads, c_k, are to be taken as 1.0. The unfactored (c_k =1.0) load combination of most unfavorable permanent loads, variable loads and the environmental loads is to be applied.

Using this method, the reinforcing stresses are to be limited in compliance with 7-3/Table 1. Additionally, for hollow structural cross sections, the maximum permissible membrane strain across the walls is not to cause cracking under any combination of unfactored loads. For structures prestressed in one direction only, tensile stresses in reinforcement transverse to the prestressing steel are to be limited so that the strains at the plane of the prestressing steel do not exceed D_{ps}/E_S, where D_{ps} is as defined in 7-3/Table 1 and E_S is the modulus of elasticity of reinforcement (see 7-3/7.3).

Alternative criteria such as those which directly limit crack width may also be considered.

5.9.2 Liquid-Containing Structures

The following criteria are to be satisfied for liquid-containing structures to verify adequate design against leakage.

i) The reinforcing steel stresses are to be in accordance with 7-3/5.9.1.

ii) The compression zone is to extend over 25% of the wall thickness or 205 mm (8 in), whichever is less.

iii) There is no membrane tensile stress unless other construction arrangements are made, such as the use of special barriers to prevent leakage.

TABLE 1
Allowable Tensile Stresses for Prestress and Reinforcing Steel to Control Cracking

Stage	*Loading*	*Allowable Stress, MPa (ksi)*	
		Reinforcing Steel, f_s	*Prestressing Tendons, D_{ps}*
Construction: where cracking during construction would be detrimental to the completed structure	All loads on the structure during construction	160 (23.0)	130 (18.5)
Construction: where cracking during construction is not detrimental to the completed structure	All loads on the structure during construction	210 (30.0) or 0.6 f_y, whichever is less	130 (18.5)
Transportation and installation	All loads on the structure during transportation and installation	160 (23.0)	130 (18.5)
At offshore site	Permanent and variable loads plus environmental loads	0.8 f_y	

f_y = yield stress of the reinforcing steel
f_s = allowable stress in the reinforcing steel
D_{ps} = increase in tensile stress in prestressing steel with reference to the stress at zero strain in the concrete.

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7 Analysis and Design *(1 July 2020)*

7.1 General

Generally, the analysis of a concrete structure may assume the use of linearly elastic materials and linearly elastic structural behavior in accordance with the requirements of ACI 318 and the additional requirements of this Subsection. The material properties to be used in analysis are to conform to 7-3/7.3. However, the inelastic behavior of concrete based on the true variation of the modulus of elasticity with stress and the geometric nonlinearities, including the effects of initial deviation of the structure from the design geometry, are to be taken into account whenever their effects reduce the strength of the floating substructure. The beneficial effects of the concrete's nonlinear behavior may be accounted for in the analysis and design of the structure to resist dynamic loadings.

7.3 Material Properties for Structural Analysis

7.3.1 Specified Compressive Strength

The specified compressive strength of concrete, f'_c, is to be based on 28-day tests performed in accordance with specifications ASTM C172, ASTM C31 and ASTM C39.

7.3.2 Early Loadings

For structures that are subjected to loadings before the end of the 28-day hardening period of concrete, the compressive strength of concrete is to be taken at the actual age of concrete at the time of loading.

7.3.3 Early Strength – Concrete

For early-strength concrete, the age for the tests for f'_c may be determined based on the cement manufacturer's certificate.

7.3.4 Modulus of Elasticity – Concrete

For the purposes of structural analyses and deflection checks, the modulus of elasticity, E_c, of normal weight concrete may be assumed as equal to $4733(f'_c)^{0.5}$ MPa ($57(f'_c)^{0.5}$ ksi), or determined from stress-strain curves developed by tests (see 5-3/Figure 1). When the latter method is used, the modulus of elasticity is to be determined using the secant modulus for the stress equal to $0.50f'_c$.

7.3.5 Uniaxial Compression – Concrete

In lieu of tests, the stress-strain relation shown in 7-3/Figure 1 may be used for uniaxial compression of concrete.

7.3.6 Poisson Ratio

The Poisson ratio of concrete may be taken equal to 0.20.

7.3.7 Modulus of Elasticity – Reinforcement

The modulus of elasticity, E_s of non-prestressed steel reinforcement is to be taken as 200 x 10^3 MPa (29 x 10^3 ksi). The modulus of elasticity of prestressing tendons is to be determined by tests.

7.3.8 Uniaxial Tension – Reinforcement

The stress-strain relation of non-prestressed steel reinforcement in uniaxial tension is to be assumed as shown in 7-3/Figure 2. The stress-strain relation of prestressing tendons is to be determined by tests, or taken from the manufacturer's certificate.

7.3.9 Yield Strength – Reinforcement

If the specified yield strength, f_y, of non-prestressed reinforcement exceeds 420 MPa (60 ksi), the value of f_y used in the analysis is to be taken as the stress corresponding to a strain of 0.35%.

7.5 Analysis of Plates, Shells, and Folded Plates

In all analyses of shell structures, the theory employed in analysis is not to be based solely on membrane or direct stress approaches. The buckling strength of plate and shell structures is to be checked by an analysis that takes into account the geometrical imperfections of the structure, the inelastic behavior of concrete and the creep deformations of concrete under sustained loading. Special attention is to be given to structures subjected to external pressure and the possibility of their collapse (implosion) by failure of concrete in compression.

7.7 Deflection Analysis

Immediate deflections may be determined by the linear structural analysis. For the purposes of deflection analysis, the member stiffness is to be computed using the material properties specified in the design and is to take into account the effect of cracks in tension zones of concrete. The effect of creep strain in concrete is to be taken into account in the computations of deflections under sustained loadings.

7.9 Analysis and Design for Shear and Torsion

The analysis and design of members subjected to shear or torsion or to combined shear and torsion is to adhere with the applicable requirements of ACI 318 or their equivalent.

7.11 Analysis and Design for Bending and Axial Loads

7.11.1 Assumed Conditions

The analysis and design of members subjected to bending and axial loads are to be based on the following assumptions:

i) The strains in steel and concrete are proportional to the distance from the neutral axis

ii) Tensile strength of the concrete is to be neglected, except in prestressed concrete members under unfactored loads, where the requirements in 7-3/5.9 apply

iii) The stress in steel is to be taken as equal to E_S (see 7-3/7.3.7) times the steel strain, but not larger than f_y (see 7-3/7.3.9)

iv) The stresses in the compression zone of concrete are to be assumed to vary with strain according to the curve given in 7-3/Figure 1 or any other conservative rule. Rectangular distribution of compressive stresses in concrete specified by ACI 318 may be used.

v) The maximum strain in concrete at the ultimate state is not to be larger than 0.30%.

7.11.2 Failure

The members in bending are to be designed in such a way that any section yielding of steel occurs prior to compressive failure of concrete.

FIGURE 1
Idealized Stress-Strain Relation for Concrete in Uniaxial Compression

E_c is defined in 5-3/7.3

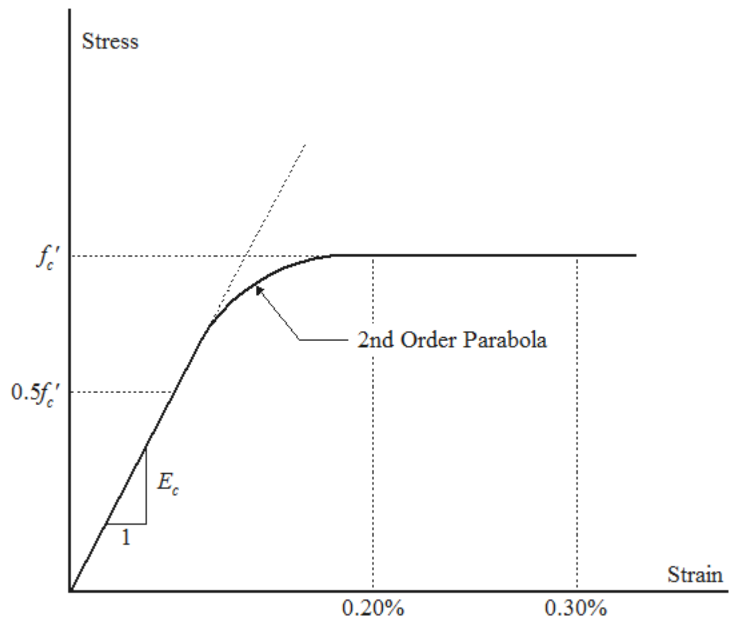
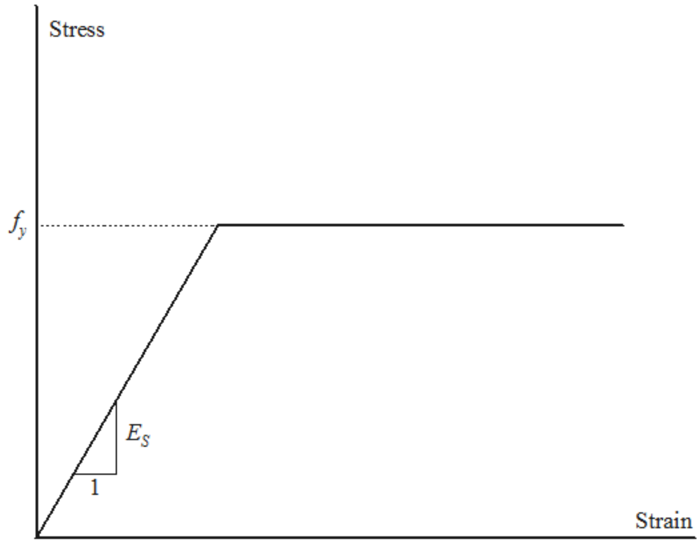


FIGURE 2
Idealized Stress-Strain Relation for Non-Prestressed Steel in Uniaxial Tension

$E_S = 200 \times 10^3$ MPa (29×10^3 ksi)



9 Design Details *(1 July 2020)*

9.1 Concrete Cover

9.1.1 General

The following minimum concrete cover for reinforcing bars is required:

i) Atmospheric zone not subjected to salt spray: 50 mm (2 in.)

ii) Splash and atmospheric zones subjected to salt spray and exposed to soil: 65 mm (2.5 in.)

iii) Submerged zone: 50 mm (2 in.)

iv) Areas not exposed to weather or soil: 40 mm (1.5 in.)

v) Cover of stirrups may be 13 mm (0.5 in) less than covers listed above

9.1.2 Tendons and Ducts

The concrete cover of prestressing tendons and post-tensioning ducts is to be increased by 25 mm (1 in.) above the values listed in 5-3/9.1.1.

9.1.3 Sections Less Than 500 mm (20 in.) Thick

In sections less than 500 mm (20 in.) thick, the concrete cover of reinforcing bars and stirrups may be reduced below the values listed in 5-3/9.1.1. However, the cover is not to be less than the following:

i) 1.5 times the nominal aggregate size

ii) 1.5 times the maximum diameter of reinforcement, or 19 mm (0.75 in.)

iii) Tendons and post-tensioning duct covers are to have 12.5 mm (0.5 in.) added to the above

9.3 Minimum Reinforcement

The minimum requirements of ACI 318 are to be satisfied. In addition, for loadings during all phases of construction, transportation, and operation (including design environmental loading) where tensile stresses occur on a face of the structure, the following minimum reinforcement is to be provided.

$$A_s = \left(f_t/f_y\right)bd_e$$

where

A_s	=	total cross-section area of reinforcement
f_t	=	mean tensile strength of concrete
f_y	=	yield stress of the reinforcing steel
b	=	width of structural element
d_e	=	effective tension zone, to be taken as 1.5c + $10d_b$
c	=	cover of reinforcement
d_b	=	diameter of reinforcement bar

d_e is to be at least 0.2 times the depth of the section, but not greater than $0.5(h - x)$, where x is the depth of the compression zone prior to cracking and h is the section thickness.

At intersections between structural elements, where transfer of shear forces is essential to the integrity of the structure, adequate transverse reinforcement is to be provided.

9.5 Reinforcement Details

Generally, lapped joints and mechanical splices are to be avoided in structural members subjected to significant fatigue loading. Where lapped splices are used in members subjected to fatigue, the development length of reinforcing bars is to be twice that required by ACI 318, and lapped bars are to be tied with tie wire. Where mechanical splices are used in members subjected to fatigue, the coupled assembly of reinforcing bars and the mechanical coupler are to demonstrate adequate fatigue resistance by test.

Where lapped bars are expected to be subjected to tension during operation, through-slab confinement reinforcement is to be considered at the splices. Where longitudinal bars are subjected to tension during operation, special consideration is to be given to number of reinforcement with splices at a single location.

Reinforcing steel is to comply with the chemical composition specifications of ACI 359 if welded splices are used.

For anchorage of shear and main reinforcement, mechanically-headed bars (T-headed bars) may be used if their effectiveness has been verified by static and dynamic testing. Shear reinforcement is to be full length without splices. Entire close-up stirrups are to be anchored by hooks or bends of at least 90 degrees followed by a straight leg length of a minimum 12 bar diameters.

9.7 Post Tensioning Ducts

Ducting for post-tensioning ducts may be rigid steel or plastic (polyethylene or polystyrene). Steel tubing is to have a minimum wall thickness of 1 mm. Plastic tubing is to have a minimum wall thickness of 2 mm. Ducts may also be semi-rigid steel, spirally wrapped, of minimum thickness of 0.75 mm, and is to be grout-tight. All splices in steel tubes and semi-rigid duct are to be sleeved and the joints sealed with heat-shrink tape. Joints in plastic duct are to be fused or sleeved and sealed.

The inside diameter of ducts is to be at least 6 mm (0.25 in.) larger than the diameter of the post-tensioning tendon to facilitate grout injection.

Flexible ducts are to be used only in special areas where the rigid or semi-rigid duct is impracticable, such as at sharp bends. A mandrel is to be inserted into the ducts to prevent them from dislocating during concreting.

9.9 Post-Tensioning Anchorages and Couplers

Anchorages for unbonded tendons and couplers are to develop the specified ultimate capacity of the tendons without exceeding the anticipated set. Anchorages for bonded tendons are to develop at least 90% of the specified ultimate capacity of the tendons, when tested in an unbonded condition without exceeding anticipated set. However, 100% of the specified ultimate capacity of the tendons is to be developed after the tendons are bonded in the member.

Anchorage and end fittings are to be permanently protected against corrosion. Post-tensioning anchorages are to preferably be recessed in a pocket which is then filled with concrete. The fill is to be mechanically tied to the structure by reinforcements as well as bonded by epoxy or polymer.

Anchor fittings for unbonded tendons are to be capable of transferring to the concrete a load equal to the capacity of the tendon under both static and cyclic loading conditions.

9.11 Embedded Metals in Concrete

Consideration is to be given to the prevention of corrosion on exposed faces of steel embedment. These embedments are to be separated from the reinforcing steel. Effects of dimensional changes due to factors such as prestressing and temperature changes which may result in fractures near embedments may require provisions to prevent deformation.

11 Construction and Detailing *(1 July 2020)*

11.1 General

Construction methods and workmanship are to follow accepted practices as described in ACI 301, ACI 318, ACI 357 or other relevant standards. Additional requirements relevant to concrete floating substructure are included below.

11.3 Mixing, Placing, and Curing of Concrete

11.3.1 Mixing

Mixing of concrete is to conform to the requirements of ACI 318 and ASTM C94.

11.3.2 Cold Weather

In cold weather, concreting in air temperatures below 2°C (35°F) is to be carried out only if special precautions are taken to protect the fresh concrete from damage by frost. The temperature of concrete at the time of placing is to be at least 4°C (40°F) and the concrete is to be maintained at this or a higher temperature until it has reached a strength of at least 5 MPa (700 psi).

Protection and insulation are to be provided to concrete where necessary. The aggregates and water used in the mix are to be free from snow, ice and frost. The temperature of fresh concrete may be raised by heating the mixing water or the aggregates or both. Cement is never to be heated, nor is it to be allowed to come into contact with water at a temperature greater than 60°C (140°F).

11.3.3 Hot Weather

During hot weather, proper attention is to be given to ingredients, production methods, handling, placing, protection and curing to prevent excessive concrete temperatures or water evaporation which will impair the required strength or serviceability of the member or structure. The temperature of concrete as placed is not to exceed 30°C (90°F) and the maximum temperature due to heat of hydration is not to exceed 65°C (145°F).

11.3.4 Curing

Special attention is to be paid to the curing of concrete in order to verify maximum durability and to minimize cracking. Concrete is to be cured with fresh water, whenever possible, to keep the concrete surface wet during hardening. Care is to be taken to avoid the rapid lowering of concrete temperatures (thermal shock) caused by applying cold water to hot concrete surfaces.

11.3.5 Sea Water

Sea water is not to be used for curing reinforced or prestressed concrete, although, if demanded by the construction program, "young" concrete may be submerged in sea water provided it has gained sufficient strength to withstand physical damage. When there is doubt about the ability to keep concrete surfaces permanently wet for the whole curing period, a heavy duty membrane curing compound is to be used.

11.3.6 Temperature Rise

The rise of temperature in concrete, caused by the heat of hydration of cement, is to be controlled to prevent steep temperature stress gradients which could cause cracking of concrete. Since the heat of hydration may cause significant expansion, members must be free to contract, so as not to induce excessive cracking. In general, when sections thicker than 610 mm (2 ft) are concreted, the temperature gradients between internal concrete and external ambient conditions are to be kept below 20°C (68°F).

11.3.7 Joints

Construction joints are to be made and located in such a way as not to impair the strength and crack resistance of the structure. Where a joint is to be made, the surface of concrete is to be thoroughly cleaned and all laitance and standing water removed. Vertical joints are to be thoroughly wetted and coated with neat cement grout or equivalent enriched cement paste or epoxy coating immediately before placing of new concrete.

11.3.8 Watertight Joints

Whenever watertight construction joints are required, in addition to the above provisions, the heavy aggregate of existing concrete is to be exposed and an epoxide-resin bonding compound is to be sprayed on just before concreting. In this case, the neat cement grout can be omitted.

11.5 Reinforcement

The reinforcement is to be free from loose rust, grease, oil, deposits of salt or any other material likely to affect the durability or bond of the reinforcement. The specified cover to the reinforcement is to be maintained accurately. Special care is to be taken to correctly position and rigidly hold the reinforcement so as to prevent displacement during concreting.

11.7 Prestressing Tendons, Ducts, and Grouting

11.7.1 General

Further guidance on prestressing steels, sheathing, grouts and procedures to be used when storing, making up, positioning, tensioning and grouting tendons can be found in the relevant sections of ACI 318, Prestressed Concrete Institute (PCI) publications, Federation Internationale de la Precontrainte (FIP) Recommended Practices, and the specialist literature.

11.7.2 Cleanliness

All steel for prestressing tendons is to be clean and free from grease, insoluble oil, deposits of salt or any other material likely to affect the durability or bond of the tendons.

11.7.3 Storage

During storage, prestressing tendons are to be kept clear of the ground and protected from weather, moisture from the ground, sea spray and mist. No welding, flame cutting or similar operations are to be carried out on or adjacent to prestressing tendons under any circumstances where the temperature of the tendons could be raised or weld splash could reach them.

11.7.4 Protective Coatings

Where protective wrappings or coatings are used on prestressing tendons, they are to be chemically neutral so as not to produce chemical or electrochemical corrosive attack on the tendons.

11.7.5 Entry of Water

All ducts are to be watertight and all splices carefully taped to prevent the ingress of water, grout or concrete. During construction, the ends of ducts are to be capped and sealed to prevent ingress of sea water. Ducts may be protected from excessive rust by the use of chemically neutral protective agents such as vapor phase inhibitor powder.

11.7.6 Grouting

Where ducts are to be grouted, all oil or similar material used for internal protection of the sheathing is to be removed before grouting. However, water-soluble oil used internally in the ducts or on the tendons may be left on, to be removed by the initial portion of the grout.

11.7.7 Air Vents

Air vents are to be provided at all crests in the duct profile. Threaded grout entries, which permit the use of a screwed connector from the grout pump, may be used with advantage.

11.7.8 Procedures

For long vertical tendons, the grout mixes, admixtures and grouting procedures are to be checked to verify that no water is trapped at the upper end of the tendon due to excessive bleeding or other causes. Suitable admixtures known to have no injurious effects on the metal or concrete may be used for grouting to increase workability and to reduce bleeding and shrinkage. The temperature of members is to be maintained above 10°C (50°F) for at least 48 hours after grouting. General guidance on grouting can be found in the specialist literature. Holes left by unused ducts or by climbing rods of slipforms are to be grouted in the same manner as described above.

CHAPTER 8

Design of Stationkeeping Systems

CONTENTS

CHAPTER 8
Design of Stationkeeping Systems

SECTION 1
General

1 General Design Requirements *(1 July 2020)*

Regardless of its type, the stationkeeping system is to be designed to

i) Maintain the position of the floating substructure within a specified limit from its reference position;

ii) Control the directional heading of the floating substructure if the orientation is important for safety or operational considerations; and

iii) Assist in maintaining the acceleration and the tilting angle at tower top within a specified limit.

Typically, there are two types of position mooring systems: a conventional spread mooring system and a single point mooring system, as defined in 8-1/3 and 8-1/5. Stationkeeping for the TLP-type floating substructure relies on the tendon system as defined in 8-1/7. Dynamic positioning and thruster-assisted systems are defined in 8-1/9. The stationkeeping system may include mooring lines or tendons, connectors and hardware, winches, piles, anchors and thrusters. For a single point mooring system, a turret, a turntable, buoys, and anchoring legs may also be part of the system.

General design considerations for the stationkeeping system are described in 3-1/3 and 3-1/15.

The design conditions and the design criteria for the stationkeeping system of the Floating Offshore Wind Turbine are specified in this Chapter. Where applicable, additional design requirements for a specific type of the stationkeeping system are to be in accordance with the following:

i) ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring* for the stationkeeping system using synthetic fiber ropes

ii) ABS *FPI Rules* Section 6-2-1 for the single point mooring system

iii) ABS *FPI Rules* 5B-2/4 and API RP 2T for the tendon system

Use of innovative designs of the stationkeeping system (configuration, material, components and equipment) that are not covered by this Guide or other existing industry standards will be specially considered by ABS.

3 Spread Mooring System *(1 July 2020)*

A spread mooring system consists of multiple catenary, semi-taut or taut mooring lines anchored to piles or drag anchors at the sea bed. The other end of each line is individually attached to the hull or attached to winches or stoppers on the floating substructure through fairleads as necessary. A mooring line may have one or more line segments, in-line buoy(s) (spring buoy) or sinker(s) (clumped weight) along the line.

5 Single Point Mooring (SPM) System *(1 July 2020)*

A single point mooring system allows the floating substructure to weathervane. Three typical types of single point mooring systems are described below.

5.1 CALM (Catenary Anchor Leg Mooring) *(1 July 2020)*

A catenary anchor leg mooring system consists of a large buoy anchored by catenary mooring lines. The floating substructure is moored to the buoy by soft hawser(s) or a rigid yoke arm, which is a structure that only allows angular relative movement between the floating substructure and the buoy.

5.3 SALM (Single Anchor Leg Mooring) *(1 July 2020)*

A single anchor leg mooring system consists of an anchoring structure with built-in buoyancy at or near the water surface and is itself anchored to the sea floor by an articulated connection. The floating substructure is moored to the anchoring structure by soft hawser(s) or a rigid yoke arm.

5.5 Turret Mooring *(1 July 2020)*

A turret mooring system consists of a number of mooring legs attached to a turret that is designed to act as part of the floating substructure, allowing only angular movement of the floating substructure relative to the turret so that the floating substructure may weathervane. The turret may be mounted internally within the floating substructure or externally. Typically, a spread mooring arrangement connects the turret to the sea floor.

7 Tendon System *(1 July 2020)*

A tendon system provides a vertical mooring system to the floating substructure by linking the hull to the foundation system.

Each tendon consists of a top section for attaching the tendon to the hull-mounted tendon porches, a tendon main body, and a bottom termination assembly for attaching the tendon to the foundation system. The tendon main body is commonly made up of steel tubulars. Any other form of tendons such as solid rods, bars or wire ropes and any other materials such as non-metallic materials and composites that meet the service requirements may also be specially considered by ABS.

The tendon main body may consist of a number of tendon elements connected by tendon connectors. Tendon connectors can be mechanical couplings, welded joints or other forms of structural connection that meets the service requirements. The tendons may also have ancillary components such as corrosion protection system components, tendon load and performance monitoring devices and VIV suppression devices.

The term “tendon”, as used in this Chapter, refers to the main body of the tendon system between the hull-mounted porch and the foundation system.

9 Redundant Mooring Systems *(1 July 2020)*

A mooring system is considered as a redundant mooring system where the strength criteria in Sections 8-2, 8-3, and 8-4, as applicable, for the intact and one line damaged conditions are satisfied and the offset and motions of the Floating Offshore Wind Turbine are within the allowable design limits.

11 Non-redundant Mooring Systems *(1 July 2020)*

A non-redundant mooring system may be adopted in the design of the Floating Offshore Wind Turbine. The mooring system is considered to be non-redundant if, under the damaged condition with one broken line as defined in 8-2/5.3, the Floating Offshore Wind Turbine cannot maintain its position required by the Operating Manual or satisfy the strength criteria for the redundant mooring system as specified in this Chapter.

CHAPTER 8
Design of Stationkeeping Systems

SECTION 2
Design Conditions

1 Overview *(1 July 2020)*

This Section outlines loading conditions and design conditions to be applied in the design of the stationkeeping system of the Floating Offshore Wind Turbine.

3 Loading Conditions

3.1 Design Load Cases

The design load cases for the strength and fatigue assessment of the stationkeeping system are to be in accordance with 5-2/3.

3.3 Survival Load Cases

The stationkeeping system is to be designed to withstand the survival load cases, as specified in 5-2/5, without compromising its intended functions.

5 Design Conditions

5.1 Intact Condition *(1 July 2020)*

Intact Condition is the design condition of the stationkeeping system, where all components of the system are intact while the Floating Offshore Wind Turbine is subjected to the design load cases.

5.3 Damaged Condition with One Broken Line *(1 July 2020)*

Damaged Condition is the design condition of the redundant mooring system, where any one of mooring lines or tendons is assumed to have been broken or removed, while the Floating Offshore Wind Turbine is subjected to the design load cases as defined in 5-2/3.5. The floating substructure is assumed to oscillate around a new equilibrium position determined after taking into account the effect of a broken line. Breakage of the mooring line or tendon that sustains the maximum load in the intact condition may not lead to the worst broken line case. The the worst scenario is to be determined by analyzing several cases of broken line, including lead line broken and adjacent line broken cases.

In addition, the damaged condition with one broken line may cause out-of-plane bending (OPB) of the chain link of the remaining mooring lines or tendons. Where relevant, the effect of such bending on the mooring or tendon interface structure on the hull is to be assessed.

Damaged Condition does not apply to a non-redundant stationkeeping system, for which an increased safety factor is required (see 8-3/3 TABLE 1).

For a system utilizing the SALM concept, the damaged condition with one broken line is not relevant. A load case considering loss of buoyancy in a damaged compartment of the SALM structure is to be analyzed to assess the integrity of stationkeeping capability.

5.5 Transient Condition with One Broken Line *(1 July 2020)*

Transient Condition is the design condition of the stationkeeping system, where breakage of a mooring line or tendon, usually the lead line, causes the moored floating substructure to exhibit transient motions (also known as overshooting) before it settles at a new equilibrium position.

The transient condition could be an important design consideration when proper clearance between the moored floating substructure and nearby structures or facilities is required. Global performance analyses for this transient condition subjected to the design load cases defined in 5-2/3.5 are to be performed. The effect of increased line tensions due to overshooting upon failure of one line are also to be considered.

Transient Condition is to be applied to a redundant TLP tendon system made of chains, wire ropes, and fiber ropes, but does not apply to a TLP tendon system made of tubular members.

Transient Condition does not apply to the non-redundant stationkeeping system.

7 Design Life *(1 July 2020)*

The design life of the stationkeeping system, which constitutes part of the Floating Offshore Wind Turbine, is to be in accordance with 3-1/5.

CHAPTER 8
Design of Stationkeeping Systems

SECTION 3
Steel Mooring and Tendon Systems

1 Analysis Methods *(1 July 2020)*

The Floating Offshore Wind Turbine is a dynamic system that is subjected to steady forces of wind, current and mean wave drift, as well as wind, current and wave-induced dynamic forces. Calculations of the maximum stationkeeping system loading are to consider various relative directions of the wind, current and wave forces appropriate to the site conditions.

Global performance analyses for the purpose of designing the stationkeeping system of the Floating Offshore Wind Turbine are to be in compliance with Chapter 6. The dynamic analysis method in either the frequency domain or the time domain, or the combination of both is to be employed to determine characteristics of dynamic responses of the Floating Offshore Wind Turbine. The calculation of steady forces due to wind, current and wave are outlined in Section 5-3.

Fatigue analysis is in general to follow the procedure described in API RP 2T for the tendon system and API RP 2SK for other types of stationkeeping system. Fatigue life of each mooring line or tendon is to be evaluated.

3 Strength Criteria for Steel Mooring Lines and Tendons *(1 July 2020)*

The steel mooring line or tendon is to be designed with the safety factors specified in 8-3/3 TABLE 1, which are to be applied to the minimum breaking strength of the mooring line or tendon. The maximum tension of a steel mooring line or tendon is not to exceed its minimum breaking strength divided by an applicable safety factor specified in 8-3/3 TABLE 1.

The safety factors in 8-3/3 TABLE 1 apply when the ‘partial safety factors’for load effects from all load categories are 1.0. These safety factors are defined for various combinations of

i) The loading conditions described in 8-2/3,

ii) The design conditions described in 8-2/5, and

iii) Redundancy of the stationkeeping system.

Additional strength design criteria for tendons made up of steel tubulars are to be in accordance with API RP 2T. Requirements of tendon minimum tension check are to be in accordance with API RP 2T.

For a TLP tendon system made of chain, tendon slack may be acceptable provided the snap loads are considered in the design. The tendon slack is to be modeled in the global performance analysis. The snap loads are to be considered in the design of chains, connectors, connection to foundation, foundation, and hull interface structure.

Allowances for corrosion and abrasion of a mooring line are to be taken into consideration following the recommendations in API RP 2SK.

TABLE 1
Safety Factors for Steel Mooring Lines or Tendons *(1 October 2015)*

Loading Condition	*Redundancy of the Stationkeeping System*	*Design Condition of the Stationkeeping System*	*Safety Factor*
Design Load Cases	Redundant	Intact	1.67
		Damaged condition with one broken line	1.05
		Transient condition with one broken line	1.05
	Non-redundant	Intact	2.0
Survival Load Cases	Redundant or Non-redundant	Intact	1.05

Notes:

1 Safety factors are to be applied to the minimum breaking strength (MBS) of the mooring line or tendon.

2 Additional strength design criteria for tendons made up of steel tubulars are to comply with API RP 2T.

3 Requirements of tendon minimum tension check are to comply with API RP 2T.

5 Fatigue Criteria for Steel Mooring Lines and Tendons *(1 July 2020)*

The calculated fatigue life of the mooring line or tendon is not to be less than the design life of the stationkeeping system times the fatigue design factors (FDFs) listed in 8-3/3 TABLE 2.

The fatigue resistance of the mooring line or tendon is to be determined in accordance with 8/7 of the ABS *Guide for Position Mooring Systems*. Suitable T-N or S-N curves are to be selected, with special attention being given to the application method and limitations of those curves.

The load combination for fatigue assessment is described in 8-2/3.1 and 5-2/3.5. A minimum set of Design Load Cases (DLCs) for fatigue assessment is specified in 5-2/3.5 TABLE 1, where “F” in the column entitled “Type of Analysis” designates the fatigue assessment. The stationkeeping system is to be considered intact in global performance analyses for the fatigue design load cases.

For the tendon, fatigue damage due to a single extreme environmental event with a return period of 50 years, as described in 5-2/5, is part of the robustness check. The unfactored damage accumulated during this event is to be equal to or less than 0.02. Such fatigue damage is not to be combined with the fatigue damage accumulation incurred by long-term environmental and operational loading.

TABLE 2
Fatigue Design Factors (FDFs) for Fatigue Life of Steel Mooring Lines or Tendons

Redundancy of the Stationkeeping System	*Inspectable and Repairable*	*Fatigue Design Factors*
Redundant	Yes	2
	No	5

Redundancy of the Stationkeeping System	*Inspectable and Repairable*	*Fatigue Design Factors*
Non-redundant	Yes	3
	No	10

7 Design of Components and Equipment *(1 July 2020)*

Typical stationkeeping system components and equipment for the Floating Offshore Wind Turbine may include winches, windlasses, chain, wire, in-line buoys, fairleads and chain stoppers. The foundation components for the stationkeeping system may include drag anchors, pile anchors, vertically loaded anchors (VLAs) or suction piles. Gravity boxes, grouted piles, templates, etc., may also be used.

Anchor design is addressed in Section 8-5. Other stationkeeping system components and equipment are to be in accordance with the applicable ABS publications and recognized industry standards as listed below:

• *Buoyancy Tanks*	ASME Boiler and Pressure Vessel Code
• *Chain and Accessories*	ABS *Guide for the Certification of Offshore Mooring Chain*
• *Single Point Mooring Equipment*	ABS *Guide for Position Mooring Systems*, Subsection 6/17
• *Winches and Windlasses*	ABS *Guide for Position Mooring Systems*, Subsection 6/11
• *Wire Rope*	API Spec 9A and API RP 9B
• *Tendon Foundation Components*	ABS *FPI Rules* Section 5B-2/4 and API RP 2T
• *Gravity boxes, grouted piles, templates*	API RP 2A
• *Clump Weight*	API RP 2SK

The design load cases for the strength and fatigue analysis of the stationkeeping system components are to be in accordance with 8-2/3.1.

When clump weights are used as mooring line components to provide desired mooring system restoring properties, the function of the clump weight is to be maintained throughout the design life of the stationkeeping system. Supporting documents and test reports are to be submitted to ABS for review. The connectors, if used to attach the clump weight to the mooring line, are to be designed with the anticipated loads, and the requirements for chain and accessories apply.

In general, the design load for the chain stopper, fairlead or tendon porch and its connection to the floating substructure is the breaking strength of the mooring line or tendon. Such design load may be reduced in the case that the mooring line or tendon breaking strength is over-designed due to other design considerations than the strength requirement. Hull structural interface with the stationkeeping system is to be designed in accordance with 7-2/11.3.3.

For the non-redundant stationkeeping system, a 20% increase is to be applied to those safety factors of strength design criteria defined for components of the redundant stationkeeping system under the intact design condition.

For the robustness check of strength using the survival load cases as referenced in 8-2/3.3, the safety factor is to be at least 1.05.

The fatigue life of the chain stopper, fairlead or tendon porch and its connection to the floating substructure, and tendon foundation components is not to be less than the design life of the stationkeeping system times the fatigue design factors (FDFs) specified in 8-3/5 TABLE 2.

The chain stoppers are to be function tested at the specified proof load to the satisfaction of the attending Surveyor.

9 Corrosion and Wear

Protection against chain corrosion and wear is normally provided by increasing chain diameters. Current industry practice is to increase the chain diameter by 0.2 mm to 0.4 mm per service year in the splash zone and in the dip or thrash zone on the hard seabed. A diameter increase of 0.1 mm to 0.2 mm per service year is typically applied to other areas of the chain.

In the strength analysis, the chain diameter for determination of required Minimum Breaking Strength (MBS) is not to include corrosion and wear margins.

In the fatigue analysis, the chain diameters associated with various service periods within the design life can be established if the corrosion rate is predictable. The chain diameter for a given service period is the nominal diameter minus the expected corrosion and wear at the end of that period. If the corrosion rate is uncertain, a conservative approach using the chain diameter excluding corrosion and wear margins is to be considered in the fatigue analysis.

Corrosions of wire rope at connections to sockets could be excessive due to the galvanized wire acting as an anode for adjacent components. It is recommended that either the wire be electrically isolated from the socket or the socket be isolated from the adjacent component. Additional corrosion protection may be achieved by adding sacrificial anodes to this area.

For the steel tendon system, a corrosion protection and control system is to be used. Guidance on design of corrosion protection and control system for steel tendon system can be found in API RP 2T.

CHAPTER 8
Design of Stationkeeping Systems

SECTION 4
Synthetic Fiber Ropes

1 Analysis Methods *(1 July 2020)*

Global performance analyses for the purpose of designing the stationkeeping system using synthetic fiber ropes as the mooring lines are to comply with Section 6. The dynamic analysis method in either the frequency domain or the time domain, or the combination of both is to be employed to account for characteristics of dynamic responses of the Floating Offshore Wind Turbine. The calculation of steady forces due to wind, wave and current are outlined in Section 5-3.

Additional analysis guidance specific to synthetic fiber ropes is provided in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*.

3 Design Criteria *(1 July 2020)*

The design load cases for the strength and fatigue analysis of the stationkeeping system using synthetic fiber ropes as the mooring lines of the Floating Offshore Wind Turbine are to be in accordance with 8-2/3.1.

The strength design is to satisfy the requirements in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*.

For the non-redundant stationkeeping system, a 20% increase is to be applied to those safety factors of strength design criteria defined in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring* for the redundant stationkeeping system under the intact design condition.

The fatigue life of synthetic fiber ropes used as the mooring lines subjected to tension-tension cyclic loads is not to be less than the design life of the stationkeeping system times the fatigue design factors (FDFs) specified in 8-3/5 TABLE 2. Additional design requirements regarding creep and compressive fatigue are to be in accordance with the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*.

For the robustness check of the strength of the mooring lines made of synthetic fiber ropes using the survival load cases as specified in 8-2/3.3, the safety factor is to be at least 1.05.

For a synthetic fiber rope connected with a torque steel wire rope, the torque match is to satisfy the applicable requirement as specified in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*.

5 Design of Components and Equipment *(1 July 2020)*

Design requirements in 8-3/7 are to be satisfied, as appropriate, for the components and equipment of the stationkeeping system using synthetic fiber ropes as the mooring lines. Additional guidance specific to synthetic fiber ropes is provided in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*.

CHAPTER 8
Design of Stationkeeping Systems

SECTION 5
Anchor Holding Power

1 Drag Anchor *(1 July 2020)*

For a catenary mooring system with drag anchors, the mooring line length is to be sufficiently long such that there is in general no angle between the mooring line and the sea floor in any design condition, as described in Section 8-2. For an anchoring site with soft clay condition, a small angle for the damaged condition with one broken line may be considered by ABS on a case-by-case basis.

Drag anchor holding power depends on the anchor type, as well as the condition of an anchor deployed in regard to penetration of the flukes, opening of the flukes, depth of burial, stability of the anchor during dragging, soil behavior of the flukes, etc. The designer is to submit the performance data for a specific anchor type and site-specific soil conditions for the estimation of the ultimate holding capacity (UHC) of an anchor design. Because of uncertainties and wide variations of anchor characteristics, exact holding power is to be determined after the anchor is deployed and load tested.

The anchor load, F_{anchor}, is to be calculated as follows. The maximum anchor load is to be determined by evaluating all design conditions described in Section 8-2. The safety factors for the holding capacity of a drag anchor are specified in 8-5/15 TABLE 2.

$$F_{anchor} = P_{line} - W_{sub}D_{water} - F_{friction}$$

$$F_{friction} = fLW_{sub}$$

where

F_{anchor}	=	anchor load, in N (lb)
P_{line}	=	mooring line tension at any design condition, in N (lb)
W_{sub}	=	submerged unit weight of the mooring line, in N/m (lb/ft)
D_{water}	=	water depth, in m (ft)
$F_{friction}$	=	holding power of the mooring line on the sea floor, in N (lb)
f	=	coefficient of friction of the mooring line on the sea floor, (dimensionless)
L	=	length of the mooring line on the sea floor, not to exceed 20 percent of the total length of a mooring line, in m (ft)

Note:

The above equation for F_{anchor} is strictly correct only for a single line having constant W_{sub} and without buoys or clump weights. Appropriate adjustments are required for other cases.

The coefficient of friction, f, depends on the soil condition and the type of mooring line. For soft mud, sand and clay, the values of f recommended by API RP 2SK for wire ropes and chains are listed in 8-5/Table 1. The static (starting) friction coefficients are normally used to determine the holding power of the mooring line on the sea floor, while the sliding friction coefficients are normally used to compute the friction force on the mooring line during mooring deployment.

Further guidance on design and insulation of drag anchors can be found in the ABS *Guidance Notes on Design and Installation of Drag Anchor and Plate Anchor.*

TABLE 1
Coefficient of Friction of the Mooring Line on the Sea Floor

	Coefficient of Friction, f	
	Static	*Sliding*
Chain	1.00	0.70
Wire Rope	0.60	0.25

3 Vertically Loaded Drag Anchor (VLA) *(1 July 2020)*

VLAs can be used in a taut line mooring system with approximately a 35 to 45 degree angle between the sea floor and the mooring line. These anchors are designed to withstand both the vertical and horizontal loads imposed by the mooring line. The structural and geotechnical holding capacity design of the VLA are to be submitted for review. The submitted design documentation is to include the ultimate holding capacity and the anchor's burial depth beneath the sea floor. Additionally, the fatigue analysis of the anchor and the connectors joining the VLA to the mooring line is to be submitted for review.

Further guidance on design and insulation of VLA can be found in the ABS *Guidance Notes on Design and Installation of Drag Anchor and Plate Anchor.*

The safety factors of VLA anchors'holding capacity are specified in 8-5/Table 2.

5 Conventional Pile

Conventional pile anchors are capable of withstanding uplift and lateral forces at the same time. Structural analysis of the pile anchor is to be submitted for review. The analyses for different types of soil using representative soil resistance and deflection (*p-y*) curves are to follow the ABS *Offshore Installations Rules*, API RP 2A, API RP 2SK and API RP 2T, as applicable. The fatigue analysis of the pile is to be submitted for review.

The safety factors for the holding capacity of a conventional pile anchor are specified in 8-5/Table 2.

7 Suction Pile

Suction pile anchors are caisson foundations that are penetrated to the target depth by pumping out the water inside the pile to create under-pressure within the pile. Suction piles generally have larger diameters and are shorter in length than conventional piles. They typically consist of a stiffened cylindrical shell with a cover plate at the top and an open bottom. These piles can be designed to have a permanent top or a retrievable top depending on the required vertical holding capacity. The padeye for the mooring line connection can be at the top or at an intermediate level depending on the application of a suction pile.

Suction pile anchors are capable of withstanding uplift and lateral forces. Due to distinctive geometry of suction pile anchors, soil failure modes relevant to the suction pile anchors may be different than those applicable for slender conventional piles. The safety factors for the suction piles' holding capacity are specified in 8-5/Table 2.

Geotechnical holding capacity and structural analyses for the suction piles are to be submitted to demonstrate the adequacy of the suction piles to withstand in-service and installation loads. Fatigue analysis of the suction piles are also to be submitted for review.

Additionally, installation analyses are to verify that the suction piles can achieve the design penetration and, if necessary, can be retrieved. It is recommended that the ratio of the force that would cause uplift of the soil-plug inside the pile to the effective pile installation force be at least 1.5 in the penetration analysis. Installation analyses results for the suction pile anchors are to be submitted for review.

9 Suction Embedded Plate Anchor *(1 July 2020)*

Suction embedded plate anchors and VLAs are both considered as plate anchors, which can be broadly categorized into drag-in and push-in plate anchors. Similar to VLAs, suction embedded plate anchors can be used in a taut line mooring system with an angle of approximately 35 to 45 degrees between the sea floor and the mooring line. Suction embedded plate anchor's fluke is embedded in a vertical position. An adequate fluke rotation is achieved during the keying process by pulling on the mooring line.

Suction embedded plate anchors are designed to withstand both vertical and horizontal loads imposed by the mooring line. The design documentation is to include the ultimate holding capacity and the anchor's burial depth beneath the sea floor. Additionally, strength and fatigue assessment of the anchor and the connectors joining the suction embedded plate anchor to the mooring line are to be performed.

Further guidance on design and insulation of suction embedded plate anchors can be found in the ABS *Guidance Notes on Design and Installation of Drag Anchor and Plate Anchor.*

The safety factors for suction embedded plate anchors' holding capacity are specified in 8-5/Table 2.

11 Dynamically Embedded Plate Anchor *(1 July 2020)*

Similar to suction embedded plate anchors, dynamically embedded plate anchors are categorized as push-in plate anchors. Similar to VLAs and suction embedded plate anchors, dynamically embedded plate anchors can be used in a taut line mooring system with an angle of approximately 35 to 45 degrees between the sea floor and the mooring line.

Dynamically embedded plate anchors are designed to withstand both vertical and horizontal loads imposed by the mooring line. The design documentation is to include the ultimate holding capacity and the anchor's burial depth beneath the sea floor. Additionally, strength and fatigue assessment of the anchor and the connectors joining the dynamically embedded plate anchor to the mooring line are to be performed.

Further guidance on design and insulation of dynamically embedded plate anchors can be found in the ABS *Guidance Notes on Design and Installation of Drag Anchor and Plate Anchor.*

The safety factors for dynamically embedded plate anchors' holding capacity are specified in 8-5/Table 2.

13 Dynamically Installed Pile Anchor *(1 July 2020)*

Dynamically installed pile anchors are capable of withstanding uplift and lateral forces at the same time. Strength assessment of the pile anchor structure is to be performed. Fatigue assessment may also be required in particularly for the mooring or tendon line attachment padeye or lug. The holding capacity of a dynamically installed pile anchor is to be determined using a suitable method, such as finite element method, with consideration of three-dimensional pile-soil interactions. Model test results may be used to augment engineering analyses. When the pile includes fins and/or appendages to increase its holding capacity, an equivalent pile diameter appropriate for the loading direction may be derived for the holding capacity analysis. When the pile reaches its ultimate capacity, the pile axial deformation is in general not to exceed 10% of the pile diameter or, if applicable, the equivalent pile diameter. In addition, the lateral deformation is in general not to exceed 10% of the pile's main body width/diameter.

Further guidance on design and installation of dynamically installed pile anchors can be found in the ABS *Guidance Notes on Design and Installation of Dynamically Installed Piles.*

The safety factors for the holding capacity of dynamically installed pile anchors are the same as those for conventional piles as specified in 8-5/Table 2.

15 Factor of Safety *(1 July 2020)*

The factors of safety for holding capacity of drag anchors, VLAs, suction and dynamically embedded plate anchors, conventional pile anchors, and suction piles are specified in 8-5/Table 2, where the factor of safety is defined as the anchor holding capacity divided by the maximum anchor load.

The required ultimate holding capacity is to be determined based on mooring line or tendon loads derived from dynamic analyses as described in 8-3/1 or 8-4/1.

TABLE 2
Factor of Safety for Anchor Holding Capacities *(1 July 2020)*

Loading Condition	*Redundancy of the Stationkeeping System*	*Anchor Type*	*Design Condition of the Stationkeeping System*	*Safety Factor*
Design Load Cases	Redundant	Drag Anchors	Intact	1.5
			Damaged condition with one broken line	1.0
		Vertically Loaded Anchors (VLAs) Suction and Dynamically Embedded Plate Anchor	Intact	2.0
			Damaged condition with one broken line	1.5
		Pile Anchors	Intact	To be in accordance with API RP 2T for the tendon foundation or API RP2 SK otherwise
			Damaged condition with one broken line	To be in accordance with API RP 2T for the tendon foundation or API RP2 SK otherwise
		Suction Piles	Intact	1.5 to 2.0* For the tendon foundation, refer to API RP 2T
			Damaged condition with one broken line	1.2 to 1.5* For the tendon foundation, refer to API RP 2T
	Non-redundant	Any Anchor Type	Intact	20% increase in the safety factor required for the redundant system using the same type of anchors and under the intact design condition
Survival Load Cases	Redundant or Non-redundant	Any Anchor Type	Intact	1.05

* *Note:* The safety factor to be used in the design is to be based on the extent of the geotechnical investigation, confidence in the prediction of soil-pile behavior, experience in the design and behavior of suction piles in the area of interest, and the inclination of the mooring line load.

CHAPTER 8
Design of Stationkeeping Systems

SECTION 6
Field Test *(1 July 2020)*

After the mooring system is deployed, each mooring line is in general required to be test loaded in accordance with 7-1-3/9 of the ABS *FPI Rules*. For all types of anchors, the attainment of design-required minimum soil penetration depth is to be verified at the site.

The field test requirements for the following anchor are to comply with 7-1-3/9 of the ABS *FPI Rules*:

- Drag anchor including high-efficiency drag anchors
- Conventional piles
- Suction piles
- Plate anchor including Vertically Loaded Anchors (VLAs), and suction and dynamically embedded plate anchor
- Dynamically installed anchors

ABS will determine the necessity of a maximum intact design tension pull test depending on the extent of the geotechnical investigation, the magnitude of loading, analytical methods used for the geotechnical design and the experience with the soils in the area of interest. If the maximum intact design tension pull tests are waived, preloading of each anchor is to reach such a level that the applied load is sufficient to develop the ultimate holding capacity of the anchor and is not to be less than the mean intact design tension. The integrity and alignment of the mooring line are also to be verified.

CHAPTER **9**

Stability and Watertight/Weathertight Integrity

CONTENTS

CHAPTER 9

Stability and Watertight/Weathertight Integrity

SECTION 1

General

1 Applicability *(1 July 2020)*

The Floating Offshore Wind Turbine is to comply with the requirements of stability and watertight and weathertight integrity specified in this Section. It is suggested that the coastal State or other governmental authorities having jurisdiction over the Floating Offshore Wind Turbine to be installed be contacted to obtain any further applicable criteria.

CHAPTER 9

Stability and Watertight/Weathertight Integrity

SECTION 2

Stability

1 General *(1 July 2020)*

The stability (righting stability) requirements specified in this Section are applicable to the floating substructures with the hull types described in 1-1/17.1.1 through 1-1/17.1.4. Any unconventional stability issues that may be specific to an innovative configuration of the Floating Offshore Wind Turbine are subject to special considerations by ABS. The concept of the requirement of the area ratio of the righting and overturning moment curves may be considered for application to the floating substructure having an unconventional hull configuration. The dynamic-response-based intact stability analysis may also be acceptable, provided that model tests are performed to validate the intact analysis results.

The floating substructure, which may carry a partial or an entire RNA depending on a specific afloat condition, is to have positive metacentric height (GM) in calm water equilibrium position for all afloat conditions during its pre-service and in-service phases. For the purpose of determining compliance with the stability requirements contained herein, the floating substructure is to be assumed free of mooring restraints except for TLP-type floating substructures. However, detrimental effects of catenary mooring systems or of the thrusters for dynamically positioned installations are to be considered as appropriate.

For TLP-type of floating substructure in the in-service condition, the stability is assessed based on global performance analysis for all DLCs defined in 5-2/Table 1.

The metacentric height is to be specified for each mode of operation and guidance is to be included in the Operating Manual on the procedure to determine and satisfy the expected metacentric height. This may be accomplished by including the minimum metacentric height in the calculation of the allowable distance from the keel to the center of gravity (KG).

3 Stability in Pre-Service Phases

3.1 Wet Tow

An intact and damage stability analysis for the wet tow to location is to be performed. The stability criteria are to be submitted for approval by ABS. The criteria are to give consideration to the specific aspects of the transit operation, including environmental conditions and coastal State requirements. Dismissal of damage stability criteria may be considered by ABS, provided the operation does not constitute a hazard to life, the environment and operations of other vessels.

3.3 Installation and Commissioning *(1 July 2020)*

During the installation and commissioning operations, the Floating Offshore Wind Turbine is to have a positive metacentric height. All relevant afloat conditions during installation or commissioning operations are to be considered.

If the Floating Offshore Wind Turbine is to accommodate personnel during these operations, the stability is to comply with in-service stability specified on 9-2/5 for the case in which the RNA is in the parked condition while the RNA, the tower and the floating substructure are subjected to the extreme storm condition with a return period of 50 years.

The installation analysis is to be submitted for review.

5 Stability in In-Service Phases *(1 July 2020)*

For the stability analysis, consideration is to be given to relevant unfavorable effects, including, but not limiting to, those resulting from the following:

i) Environmental conditions, such as wind, wave (including green water effects, if applicable), current, and snow and ice accumulation

ii) Applicable damage scenarios (including owner-specified requirements)

iii) Motions of the floating substructure in six degrees of freedom

iv) Effects of various turbine RNA operation conditions

v) Effects of the turbine control system

vi) Effects of the stationkeeping system

vii) Free-surface effects in ballast tanks

Stability calculations are to reflect the actual configuration of the Floating Offshore Wind Turbine while afloat. Free flooding compartments are not to be accounted for in the stability assessment. In the case where the permanent ballast is installed in a free flooding compartment, the net weight of the permanent ballast (using the in-water density) is to be included in the loading calculation.

5.1 Intact Stability *(1 July 2020)*

The intact stability of the floating substructure carrying the RNA and the tower is to satisfy either the intact stability criteria specified in 9-2/5.1.1 or the dynamic-response-based intact stability criteria specified in 9-2/5.1.2. Other standards may be acceptable for uncommon operations, provided due consideration is given to hazards associated with those operations. Such operations and standards are to be submitted to ABS for approval.

5.1.1 Intact Stability Criteria *(1 July 2020)*

The floating substructure carrying the RNA and the tower is to have sufficient stability to withstand the overturning moment equivalent to the one produced by any operational and extreme design load conditions, which are represented by the Design Load Cases (DLCs) for the in-service phase and with the 'Type of Analysis' designated as 'S' in 5-2/3.5 TABLE 1. As a minimum, the following design conditions are to be considered in the calculation of the overturning moment.

i) The RNA is in power production and subjected to the wind speed V_r and V_{out}, respectively, and the extreme turbulence model (ETM). See DLC1.3 in 5-2/3.5 TABLE 1. An example overturning moment curve is depicted in 9-2/5.1.1 FIGURE 1 for the case where the turbine RNA is initially in the power production mode but shuts down after the inclination angle exceeds its operating limit. Where relevant, the effect of shutdown (DLC 4.1, 4.3, and 5.1 in 5-2/Table 1) on the overturning moment curve during the transition from the power production mode to the parked condition is to be included.

ii) The RNA is in the parked condition. The RNA, the tower and the floating substructure are subjected to the extreme storm condition with a return period of 50 years (see DLC6.2 in 5-2/3.5 TABLE 1). An example overturning moment curve shown in 9-2/5.1.1 FIGURE 2 represents the case where the RNA is parked and subjected to the storm wind condition.

iii) The RNA is in the parked condition with fault. The RNA, the tower and the floating substructure are subjected to the extreme storm condition with a return period of 1 year (see DLC7.1 in 5-2/3.5 TABLE 1). An example overturning moment curve is shown in 9-2/5.1.1 FIGURE 2.

The overturning moment is to be calculated in accordance with 9-2/5.5.

For the Spar-type floating substructure, the righting energy (area under the righting moment curve) at the inclination angle of 30 degrees is to reach a value of not less than 30% in excess of the area under the overturning moment curve to the same limiting angle. In all cases, the righting moment curve is to be positive over the entire range of angles from upright and all downflooding angles are to be greater than 30 degrees.

For other types of the floating substructure under free-floating conditions, the righting energy (area under the righting moment curve) at or before the angle of the second intercept of the righting and the overturning moment curves or the downflooding angle, whichever is less, is to reach a value of not less than 30% in excess of the area under the overturning moment curve to the same limiting angle. In all cases, the righting moment curve is to be positive over the entire range of angles from upright to the second intercept angle.

For the TLP-type floating substructure in in-service conditions, the stability is typically provided by the pretension and stiffness of the tendons, rather than by the righting moments. The positive tendon tension is to be maintained. Where applicable, the effect of tendon slacking is to be taken into account. The intact condition is to include the full range of possible center of gravity variations permitted by acceptable operating procedures.

Additional considerations, when applicable, are to be given to the inclination limits imposed by the design or operational requirement of the RNA and tower, the global performance requirement, or the design requirement of the stationkeeping system.

FIGURE 1
Intact Stability Curve for the RNA in Power Production

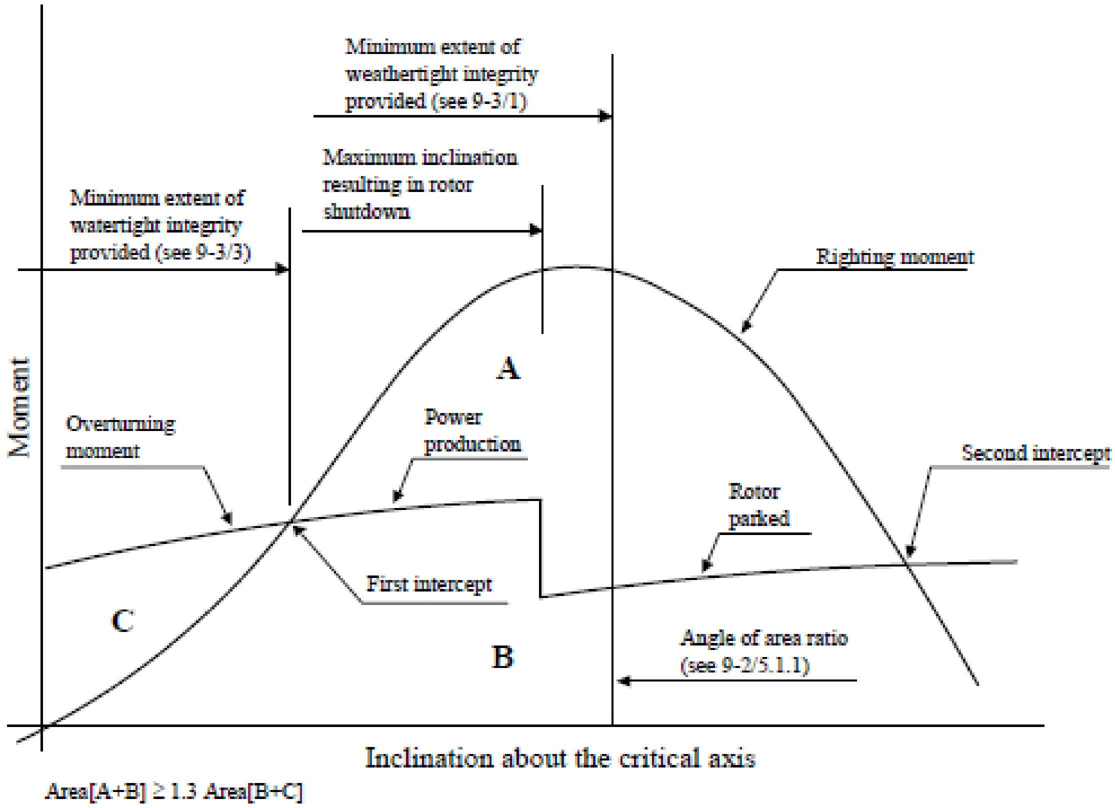
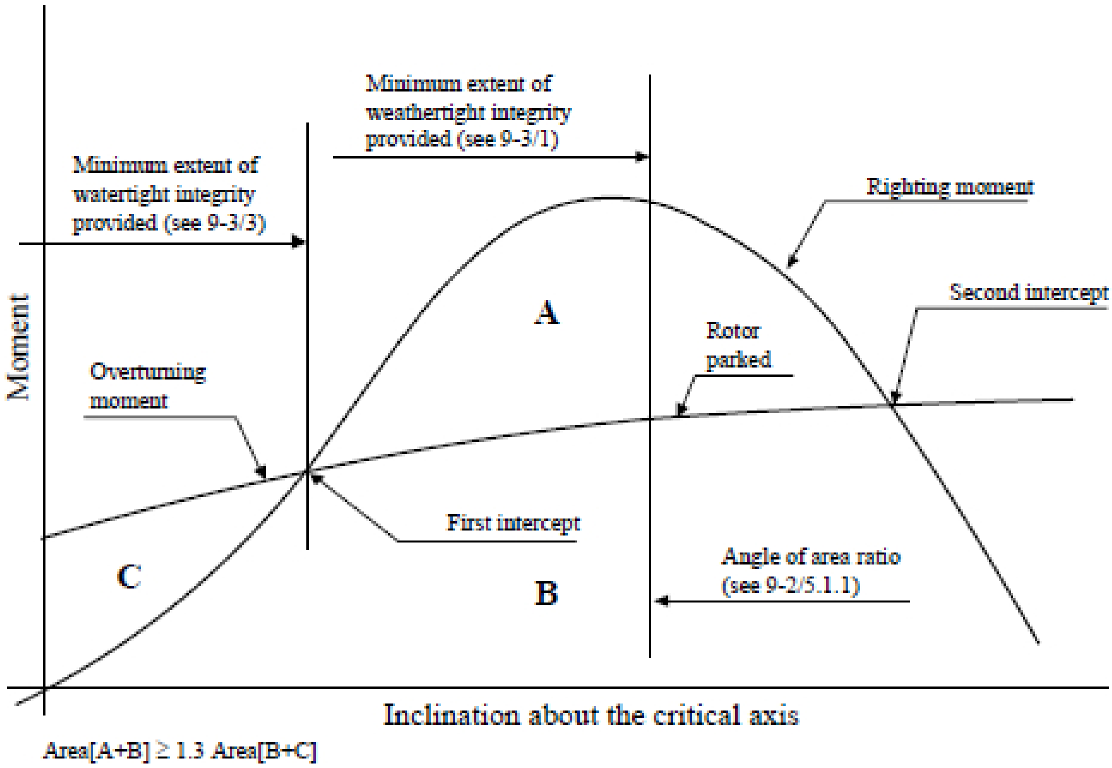


FIGURE 2
Intact Stability Curve for the Parked RNA



5.1.2 Dynamic-Response-Based Intact Stability Criteria *(1 July 2020)*

As an alternative to the intact stability criteria specified in 9-2/5.1.1, the dynamic-response-based intact stability criteria provides a rational safety margin against capsize and downflooding by incorporating the dynamic motion response characteristics into the stability criteria. The dynamic-response-based criteria described in this Subparagraph are not applicable for the TLP-type floating substructure in in-service conditions, where the stability is typically provided by the pretension and stiffness of the tendons. See 9-2/5.1.1.

Dynamic motion analyses are to be conducted for the operational and extreme design load conditions, which are represented by the Design Load Cases (DLCs) for the in-service phase and with the 'Type of Analysis' designated as 'S' in 5-2/3.5 TABLE 1. For each design load case associated with extreme storm conditions, both wind dominated (peak wind) and wave dominated (peak wave) cases, along with their associated other environmental conditions, are to be considered.

Dynamic motion analyses for assessing capsize and downflooding in free-floating conditions are in general to follow the requirements specified in Chapter 6, except that the restoring effects of the stationkeeping systems are to be excluded for the DLCs related to the RNA in normal shutdown, emergency stop or parked conditions.

The dynamic responses required as the input for the intact stability assessment include:

- For assessing the capsize criterion, maximum heel angle (θ_{max}) of the floating substructure; and
- For assessing the downflooding criterion, maximum reduction in downflooding distance (*RDFD*) due to tilting of the floating substructure and motions of the floating substructure relative to wave

5.1.2(a) Capsize

For all orientation angles, the area under the righting moment curve measured between θ_{max} and θ_2 (Area B as shown in 9-2/5.1.2 FIGURE 3) is not to be less than 10 percent of the area under the same curve measured between θ_1 and θ_{max} (Area A as shown in 9-2/Figure 3), where θ_1 and θ_2 are the inclination angles at the first and the second intercepts of the righting and the overturning moment curves. The overturning moment is to be determined according to 9-2/5.1.1.

5.1.2(b) Downflooding

For all downflooding openings, the maximum reduction in downflooding distance, *RDFD*, is to be not greater than the initial downflooding distance, DFD_0, as depicted in 9-2/5.1.2 FIGURE 4. Downflooding openings are those openings which may be required to remain open or which are not fitted with, as a minimum, an automatic weathertight closure.

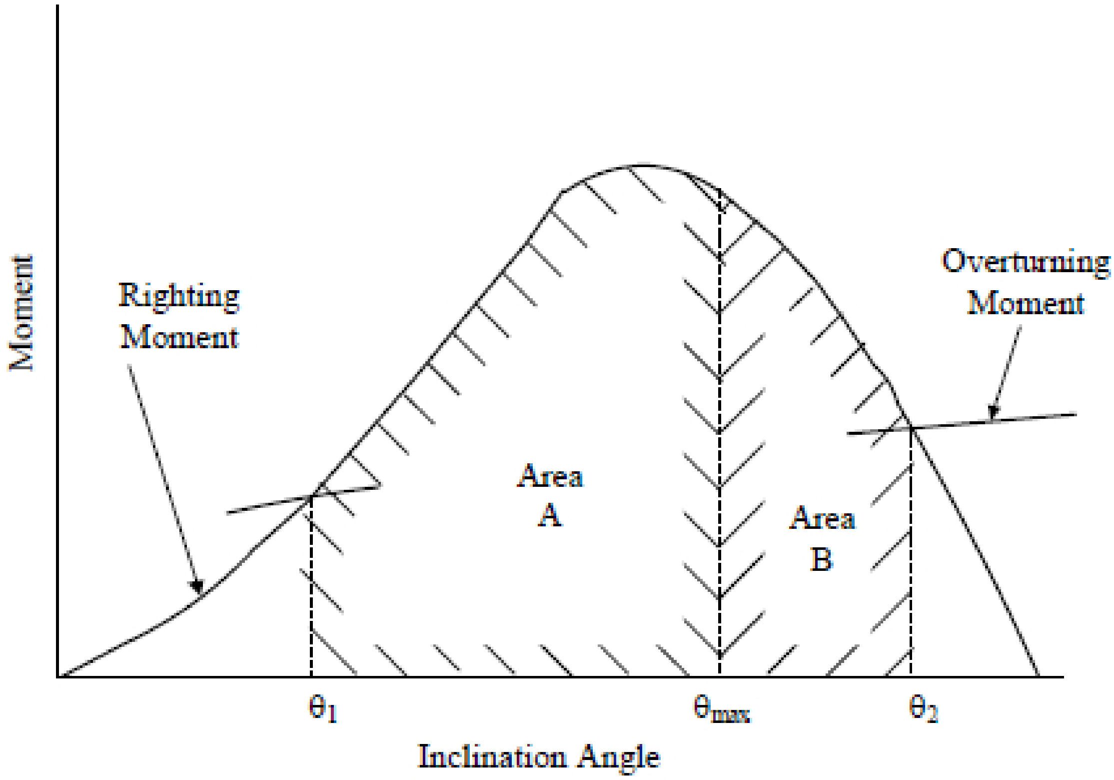
5.1.2(c) Model Tests (1 July 2020)

When comparably model test results are not available, model tests for a specific type of Floating Offshore Wind Turbine carrying a specific design of the RNA are to be performed to calibrate analytical tools and verify simulation results for the purpose of assessing the intact stability based on the dynamic-response-based criteria in 9-2/5.1.2(a) and 9-2/5.1.2(b). The following information of model tests is to be submitted to ABS for review:

- Description of model configurations, scaling methods, model RNA control scheme and instrumentation plan
- Description of input and measured wind and wave spectra
- Description of turbine operating conditions considered in model tests
- Response spectra and Response Amplitude Operators (RAOs), presented in tabular form for an appropriate range of periods (or frequencies)

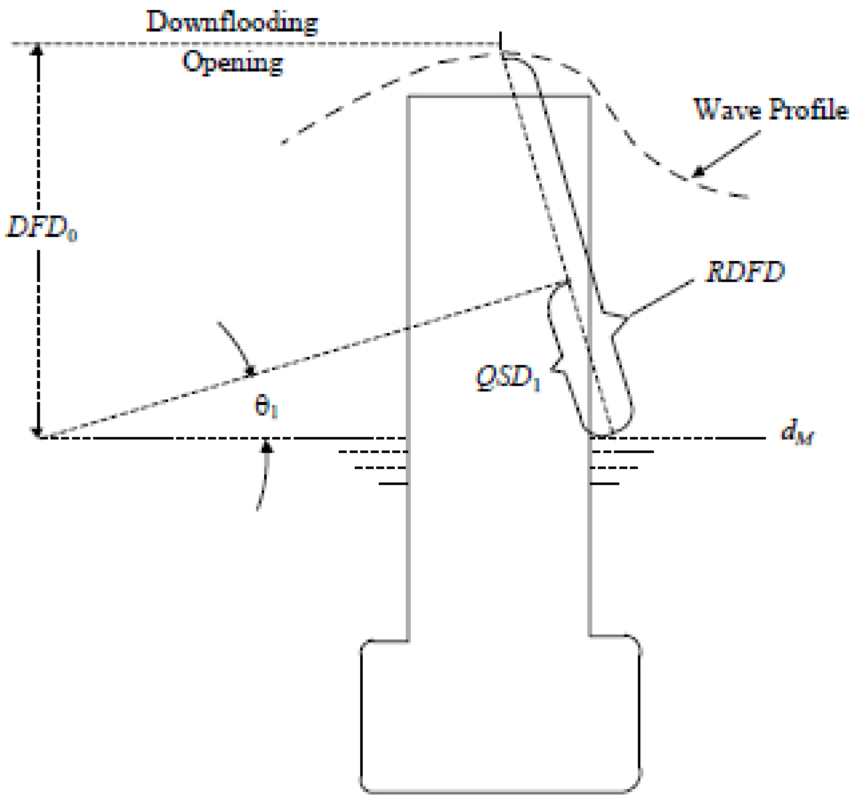
- Model test motion results, including mean, maximum, root mean square and significant values, for six degrees-of-freedom motion and relative motion for at least four reference points on the hull, along with the mooring line tensions corresponding to those motions

FIGURE 3
Capsize Criterion



Area B/Area A ≥ 0.10

FIGURE 4
Downflooding Criterion



DFD_0	: downflooding distance to initial waterline
QSD_1	: reduction in downflooding distance due to static heeling
RDFD	: maximum reduction in downflooding distance

5.3 Damage Stability *(1 July 2020)*

Any single watertight compartment, as listed in the following, located wholly or partially below the draft associated with any mode of operation afloat is to be assumed independently flooded, regardless of exposure and source of the assumed flooding.

i) A compartment containing pumps used for the handling of water ballast, or

ii) A compartment containing machinery with a sea water cooling system, or

iii) A compartment adjacent to the sea.

For the TLP-type floating substructure, flooding in any one tendon compartment independently is also to be considered.

Where access openings are fitted on watertight divisions between compartments to provide access to one or more compartments, the compartments are to be assumed flooded simultaneously, unless the following measures are taken to avoid operations that can result in the accidental flooding of such compartments when the covers are removed:

i) Warning (or Notice) plates (e.g., "Watertight Door (or Hatch) – Keep Closed") are placed on the access opening covers.

ii) Instructions and warnings are provided in the Operating Manual.

iii) System locks are available to prevent unintentional ballasting operations, where either compartment is designed for use as a ballast tank.

iv) Documented procedures are in place addressing how to avoid progressive flooding, and outlining actions necessary to maintain the stability of the floating substructure during repair operations offshore or during transit to a repair facility.

For the purpose of assessing damage stability, the overturning moments equivalent to that exerted on the floating substructure, the tower and the RNA in DLC 9.3 and DLC 10.3 are to be considered. The overturning moment is to be calculated according to 9-2/5.5.

The final waterline of the damaged floating substructure, which is assumed to sustain the one-compartment damage and subjected to the overturning moment described above for assessing the damage stability, is to:

i) Not exceed the level to which watertight integrity is to be maintained as shown on the diagrams submitted in accordance with 1-1/11.5

ii) Not exceed the lowest point of the hull main deck or the top of the buoyant hull, whichever is lower

iii) Be at least 1.5 m (5 ft) below any unprotected opening that could lead to further flooding of the hull

For the TLP-type floating substructure, positive tendon tensions are to be maintained when the one-compartment damage and the overturning moment described above in this Subsection are applied. The ability to compensate for damage incurred by pumping out or ballasting other compartments is not to be considered when determining whether positive tendon tensions can be maintained.

A description of the survival capabilities after damage is to be included in the Operating Manual.

5.5 Overturning Moment *(1 July 2020)*

Environmental conditions and RNA operating modes to be considered in calculating the overturning moment are specified in 9-2/5.1.1 and 9-2/5.3 for assessing the intact and damage stability, respectively.

For the purpose of stability calculations, the overturning moment due to wind loads calculated in accordance with 5-3/3 is to be determined at several angles of inclination for each mode of operation. The rotor thrust force is to be calculated with due consideration of characteristics of a specific design of turbine rotor, effects of RNA operating conditions, and actions of turbine's control system. The calculation is to be performed in a manner to reflect the range of stability about the critical axis. The lever arm for the overturning force is to be taken vertically from the center of lateral resistance or, if available, the center of hydrodynamic pressure of the underwater body to the center of pressure of the areas subjected to wind loading.

Overturning force and center of pressure derived from wind tunnel tests using a representative model of the Floating Support Structure and the RNA may be considered alternatively. The wind profile adopted for wind tunnel tests is to comply with 4-2/3 or use a more conservative profile.

In the case that the current force increases the overturning moment, the adverse effect of the current is to be considered in the overturning moment calculation. The current force exerted on the hull is to be calculated according to 5-3/7.

For the dynamically-positioned Floating Offshore Wind Turbine, the overturning moment is to be calculated using the sum of a wind force up to the aggregate thrust of the thruster system in each direction analyzed with a lever arm equal to the distance from the center of wind pressure to the center of the thruster propeller disc. The overturning moment due to the remaining wind force (if any) is to be calculated using a lever arm equal to the distance from the center of wind pressure to the center of lateral resistance. For this purpose, the aggregate thrust needs not to be taken greater than the wind force.

The overturning moment due to other unfavorable environmental effects, such as snow and ice accumulation and green water, and the unfavorable effect of the stationkeeping system, as described in 9-2/5 are to be considered as appropriate.

7 Weight Control *(1 July 2020)*

An inclining test or an equivalent weighing procedure established by a combination of a hull lightweight survey, measurement of permanent ballast and weighing of the major components is to be conducted to accurately determine the weight and the position of the center of gravity of the Floating Offshore Wind Turbine. The lightweight and center of gravity are in general to be determined by an inclining test. In some cases, the configuration of the Floating Offshore Wind Turbine can make inclining the structure unfeasible or impractical. In such case, the lightweight and its center of gravity are to be determined by a combination of a thorough lightweight survey and calculations.

If the inclining test is conducted, it is required for one Floating Offshore Wind Turbine per each specific design to determine the lightweight and position of center of gravity, when as near to completion as practical. An inclining test procedure is to be submitted for review prior to the test. The inclining test is to be witnessed by the Surveyor. For the same type of the Floating Offshore Wind Turbine , which are considered by ABS to be identical with regard to hull form and arrangement, with the exception of minor changes in machinery, outfit, etc., detailed weight calculations showing only the differences of weight and centers of gravity will be satisfactory, provided the accuracy of the calculations is confirmed by a lightweight survey. The results of the inclining test, or lightweight survey and inclining test adjusted for weight differences, are to be submitted for review. Changes of onboard load conditions after the inclining test and during service are to be carefully accounted for. The results of the inclining experiment and lightweight survey are to be broken into the independent components of the Floating Offshore Wind Turbine (columns, deck, tower, etc.) and are to indicate clearly the position of these components.

Weighing is to be supported by calculated weights, and to include a combination of afloat lightweight surveys and use of certified load cells to the satisfaction of the attending Surveyor. When the vertical position of the center of gravity of each component cannot be measured, it is to be placed on an indisputably conservative location with due consideration of the calculated position. Where the permanent ballast is installed, at least two (2) separate measures of the permanent ballast are to be performed.

A global weighing plan and procedures for each individual weighing, together with the weight calculations, are to be submitted for approval. Reports of the weighing are to be submitted for review. The Operating Manual is to provide guidance for the maintenance of a weight change log.

For the TLP-type floating substructure, the Operating Manual is to provide guidance for the periodical correlation between calculated and measured tendon tension.

CHAPTER 9
Stability and Watertight/Weathertight Integrity

SECTION 3
Watertight/Weathertight Integrity

1 General

A plan, identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures, and unprotected openings is to be submitted for review. Upon satisfactory review, the plan is to be incorporated into the Operating Manual.

3 Weathertight Integrity

All external openings whose lower edges are below the levels to which weathertight integrity is required to be maintained as shown on the diagrams submitted in accordance with 1-1/11.5 are to have weathertight closing appliances. Openings fitted with closing appliances to maintain weathertight integrity are to effectively resist the ingress of water due to intermittent immersion of the closure.

5 Watertight Integrity

Suitable closing appliances are to be fitted to achieve watertight integrity for all internal and external openings whose lower edges are below the levels to which watertight integrity is to be maintained for both intact and damaged conditions as shown on the diagrams submitted in accordance with 1-1/11.5. For additional watertight integrity requirements, see 3-3-2/5.3 of the *MOU Rules*.

7 Penetrations

See 3-3-2/5.5 of the *MOU Rules*.

CHAPTER 10

Machinery, Equipment and Systems

CONTENTS

CHAPTER 10

Machinery, Equipment and Systems

SECTION 1

Design Requirements

1 General (1 July 2020)

This Section provides requirements for onboard machinery, equipment, and systems.

3 Marine Piping Systems (1 July 2020)

Marine piping systems are those systems that may be required for maintaining the normal operations of the Floating Offshore Wind Turbine (such as power generation, bilge, ballast, tank venting and sounding, etc.). 4-2-1/3 of the *MOU Rules* provides the definitions of these systems.

Marine piping systems are to be in accordance with the requirements of the *MOU Rules*, except as modified in this Subsection.

3.1 Bilge System (1 July 2020)

The design of bilge systems is to meet the applicable requirements in Section 4-2-4 of the *MOU Rules*. If portable power-driven pumps are used, in lieu of a permanent bilge system, at least twosuch pumps are to be provided and are to be stored onboard or carried by the attending service vessel. All pumps and arrangements for pumping are to be readily accessible.

3.3 Ballast System

The system fitted is to provide the capability to ballast and deballast all ballast tanks that are not used as permanent ballast tanks. All pumps and valves are to be fitted with a remote means of operation. The normal or emergency operation of the ballast system is not to introduce a greater risk of progressive flooding due to the opening of hatches, manholes, etc. in watertight boundaries.

3.3.1 Pumping Systems

Where ballast systems powered by pumping systems are installed, at least two ballast pumps are to be provided, one of which is to be permanently connected to the ballast system. The second pump may be a spare held in reserve or an eductor type arrangement permanently connected to the system. If submersible ballast pumps are installed in each ballast tank, one spare pump must be stored onboard at all times.

3.3.2 Compressed Air Systems (1 July 2020)

Where a ballast system powered by compressed air is installed, a satisfactory quantity of compressed air is to be available to the system at all times.

If two compressors are installed, one compressor is to be powered by either the emergency switchboard or a dedicated engine. Each compressor is to be capable of providing 100% of the required quantity of compressed air, as specified below. If only one compressor is provided, this compressor is to be powered by either the emergency switchboard or a dedicated engine, and a quantity of stored compressed air equivalent to the required capacity specified below is to be provided.

The required quantity of compressed air is the amount of air capable of bringing the installation from its worst-case flooding condition, as defined by 9-2/5.3, to the normal operating draft and inclination.

3.5 Vents and Sounds

Except for those compartments that are not fitted with a fixed means of drainage, vent pipes are to be fitted on all tanks, cofferdams, voids, tunnels and compartments which are not fitted with other ventilation arrangements.

The requirements for sounding are to comply with the *MOU Rules*. However, to prevent duplication of pipe runs, it will be acceptable to sound the void spaces through the vent lines. In the case of a sealed vent, a sounding plug is to be provided to permit void space sounding.

5 Electrical Systems *(1 July 2020)*

The design criteria of electrical systems associated with marine systems are to be in accordance with applicable requirements described in Part 4, Chapters 1 and 3 of the *MOU Rules*. Floating Offshore Wind Turbines are not typically provided with an emergency generator. There is typically a small battery installation that supports the required emergency loads. Some floating substructures are column stabilized and are provided with ballast systems that trim the floating offshore wind turbine in order to optimize the wind turbine performance. The designer is to verify that the ballast system, or failure of the ballast system, does not affect safety or stability. Where verified, the eighteen hours for ballast pumps and control system emergency power is not applicable.

7 Fire Fighting Systems and Equipment *(1 July 2020)*

Fire fighting systems and equipment are to be designed with consideration of the size, type and intended service of the Floating Offshore Wind Turbine. As a minimum, portable extinguishers are to be provided in the quantities and locations in accordance with the applicable requirements in 5-2-4/3.17 TABLE 1 and 5-2-4/3.17 TABLE 2 of the *MOU Rules*. In all cases, the selection of the fire extinguishing medium is to be based on the fire hazard for the space protected. The fire extinguishers are to be visible and readily accessible. The plans and specifications of fire fighting systems and equipment are to be submitted according to 1-1/11.9.3.

Attention is drawn to the relevant requirements of the coastal State or other governmental authorities having jurisdiction over the Floating Offshore Wind Turbine to be installed.

9 Safety Outfitting *(1 July 2020)*

Safety outfitting and measures are to be designed with suitable consideration of the nature of unmanned installations. It is suggested that the coastal State or other governmental authorities having jurisdiction over the Floating Offshore Wind Turbine to be installed be contacted to obtain applicable requirements.

All accessible spaces that require inspection are to be provided with ladders for safe access.

11 Identification Marks *(1 July 2020)*

A unique name or number is to be assigned to each Floating Offshore Wind Turbine, which is to conform to requirements of the coastal State or other governmental authorities having jurisdiction over the Floating

Offshore Wind Turbine. This name or number is to be permanently displayed on the structure and will be entered in the ABS *Record*. Draft marks are to be permanently marked in at least two (2) places on the outside of the floating substructure indicating maximum permissible draft.

CHAPTER 11

Surveys

CONTENTS

CHAPTER 11
Surveys

SECTION 1
Surveys During Construction, Installation and Commissioning

1 General *(1 July 2020)*

This Section pertains to surveys and inspections during construction, installation and commissioning of the Floating Offshore Wind Turbine including all the items within the scope of classification (see 1-1/3). The documentation requirements for review are given in Section 1-1 of this Guide. A general quality plan highlighting required surveys together with ABS hold points is to be determined by the Fabricator or Owner and agreed upon by the attending Surveyor.

For the RNA and tower, the survey scope includes the following two situations:

- The optional **RNA** notation is requested by the Owner. The RNA and tower including its end connections are type approved by ABS and are within the scope of classification and survey.
- The optional **RNA** notation is not requested by the Owner. However, the tower and its connection to the RNA and/or to the floating substructure are not included in the wind turbine type certificate. In this scenario, the tower and its connection are within the scope of classification and survey. The RNA with a wind turbine type certificate is not within the scope of classification.

3 Construction Surveys

3.1 Scope *(1 July 2020)*

This Subsection pertains to surveys and testing to be carried out during construction of the Floating Offshore Wind Turbine at the builder's yard or facility.

3.3 Survey at Vendor's Shop *(1 July 2020)*

During construction of equipment components for a Floating Offshore Wind Turbine, the attending Surveyor is to have access to vendors' facilities to witness construction and/or testing, as required by this Guide. The vendor is to contact the attending Surveyor to make necessary arrangements. If the attending Surveyor finds reason to recommend repairs or additional surveys, notice will be immediately given to the Owner or Owner's Representative so that appropriate action may be taken. Coordination of the vendors' certification program is carried out through ABS' Vendor Coordinators.

Survey requirements for equipment components and packaged units at the vendor's shop are summarized in relevant sections of applicable ABS Rules/Guides. Each vendor is to have an effective quality system which is to be verified by the attending Surveyor.

3.5 Structure Fabrication/Erection *(1 July 2020)*

A quality control program compatible with the type and size of the planned Floating Offshore Wind Turbine is to be developed and submitted to ABS for review. ABS will review, approve and, as necessary, request modification of this program. The Fabricator is to work with the attending Surveyor to establish the required hold points on the quality control program to form the basis for future surveys at the fabrication yard. As a minimum, the items enumerated in the various applicable Subsections below are to be covered by the quality control program. The Surveyor will be assigned to monitor the fabrication of items within the scope of classification, and to verify that competent personnel are carrying out the tests and inspections specified in the quality control program. It is to be noted that the monitoring provided by ABS is a supplement to and not a replacement for inspections to be carried out by the Fabricator or Owner.

During construction, the Surveyor is to have access to structures at all reasonable times. The attending Surveyor is to be notified as to when and where parts of the structure may be examined. If, at any visit, the Surveyor finds occasion to recommend repairs or further inspection, notice is to be made to the Fabricator or its representatives.

The Fabricator is to maintain a system of material traceability to the satisfaction of the attending Surveyor for all Special and Primary Application Structures. Data as to place of origin and results of relevant material tests for structural materials are to be retained and made readily available during all stages of construction. Such data are to be available to the Surveyor upon request.

Where equipment and components are assembled in blocks or modules, the Surveyor is to inspect the fit-up, piping and electrical connections, and to witness the required tests on the completed assembly in guidance with the quality control program and in accordance with the approved plans and Rule/Guide requirements. The progress and suitability of structural fit-up and joining of constructed/fabricated blocks/modules are to be to the satisfaction of the attending Surveyor. All principal erection joints are subject to visual examination, proven tight, and the extent of Non-Destructive Examination (NDE) carried out is to be to the satisfaction of the attending Surveyor.

3.7 Surveys on Steel Structures

3.7.1 Quality Control Program *(1 July 2020)*

The quality control program for the construction of the steel Floating Offshore Wind Turbine is to include the following items, as appropriate.

i) Material quality and traceability

ii) Steel forming

iii) Welder qualification and records

iv) Welding procedure specifications and qualifications

v) Weld inspection

vi) Tolerances alignments and compartment testing

vii) Corrosion control systems

viii) Tightness and hydrostatic testing procedures

ix) Nondestructive testing

x) Verification of SCIPs as defined in 1-1/17.3.31

The items which are to be considered for each of the topics mentioned above are outlined in 11-1/3.7.2 through 11-1/3.7.10.

3.7.2 Material Quality and Traceability

The properties of the material are to comply with Chapter 2 of this Guide. Manufacturer's certificates are to be supplied with the material. Verification of the material's quality is to be done by the Surveyor at the plant of manufacture, in accordance with relevant ABS Rules/Guides. Alternatively, material manufactured to recognized standards may be accepted in lieu of the above steel requirements provided the substitution of such materials is approved by ABS. Materials used are to be in accordance with those specified in the approved design and all materials required for classification purposes are to be tested in the presence of the Surveyor. The Fabricator is to maintain a material traceability system for all the Primary and Special Application structures.

3.7.3 Steel Forming

When forming changes base plate properties beyond acceptable limits, appropriate heat treatments are to be carried out to re-establish required properties. Unless approved otherwise, the acceptable limits of the reestablished properties are to meet the minimums specified for the original material before forming. As required, ABS will survey formed members for their compliance with the forming dimensional tolerances required by the design.

3.7.4 Welder Qualification and Records *(1 July 2020)*

Welders who are to work on the structure are to be qualified in accordance with the welder qualification tests specified in a recognized code or, as applicable, Chapter 2 of this Guide to the satisfaction of the attending Surveyor. Certificates of qualification are to be prepared to record evidence of the qualification of each welder qualified by an approved standard/code, and such certificates are to be available for the use of the Surveyor. If welders have been previously tested in accordance with the requirements of a recognized code and provided that the period of effectiveness of the previous testing has not lapsed, these previous welder qualification tests may be accepted.

3.7.5 Welding Procedure Specifications and Qualifications

Welding procedures are to be approved in accordance with Chapter 2 of this Guide. Welding procedures conforming to the provisions of a recognized code may, at the Surveyor's discretion, be accepted. A written description of all procedures previously qualified may be employed in the structure’s construction provided it is included in the quality control program and made available to the Surveyor. When it is necessary to qualify a welding procedure, this is to be accomplished by employing the methods specified in the recognized code, and in the presence of the Surveyor.

3.7.6 Weld Inspection

As part of the overall quality control program, a detailed plan for the inspection and testing of welds is to be prepared. This plan is to include the applicable provisions of this Guide.

3.7.7 Tolerances and Alignments

The overall structural tolerances, forming tolerances, and local alignment tolerances are to be commensurate with those considered in developing the structural design. Inspections are to be carried out to verify that the dimensional tolerance criteria are being met. Particular attention is to be paid to the out-of-roundness of members for which buckling is an anticipated mode of failure. Structural alignment and fit-up prior to welding are to be monitored to promote consistent production of quality welds.

3.7.8 Corrosion Control Systems

The details of any corrosion control systems employed for the structure are to be submitted for review. Installation and testing of the corrosion control systems are to be carried out to the satisfaction of the attending Surveyor in accordance with the approved plans.

3.7.9 Tightness and Hydrostatic Testing Procedures *(1 July 2020)*

Compartments which are designed to be permanently watertight or to be maintained watertight during installation including all openings and penetrations are to be tested by a procedure approved by the attending Surveyor. The *MOU Rules* 7-1-2/23 may be used where applicable. The testing is also to be witnessed by the attending Surveyor.

3.7.10 Nondestructive Testing *(1 July 2020)*

A system of nondestructive testing is to be included in the fabrication specification of the structures. The minimum extent of nondestructive testing is to comply with the ABS *Guide for Nondestructive Inspection* or recognized design Code. All nondestructive testing records are to be reviewed and approved by the attending Surveyor. Additional nondestructive testing may be requested by the attending Surveyor if the quality of fabrication is not conforming to industry standards.

3.9 Surveys on Concrete Structures

3.9.1 Quality Control Program

The quality control program for a concrete structure is to cover the following items, as appropriate.

i) Inspections prior to concreting

ii) Inspection of batching, mixing and placing concrete

iii) Inspections of form removal and concrete curing

iv) Inspection of prestressing and grouting

v) Inspection of joints

vi) Inspection of finished concrete

vii) Tightness and hydrostatic testing as applicable (see 11-1/3.7.9)

The items which are to be considered for each of the topics mentioned above, except for *vii)*, are indicated in 11-1/3.9.2 through 11-1/3.9.7.

3.9.2 Inspections Prior to Concreting

Prior to their use in construction, the manufacturers of cement, reinforcing rods, prestressing tendons and appliances are to provide documentation of the pertinent physical properties. These data are to be made available to the attending Surveyor for verification of conformity with the properties specified in the approved design.

As applicable, at the construction site, the Surveyor is to be satisfied that proper consideration is being given to the support of the structure during construction, the storage of cement and prestressing tendons in weathertight areas, the storage of admixtures and epoxies to manufacturer's specifications, and the storage of aggregates to limit segregation, contamination by deleterious substances and moisture variations within the stock pile.

Forms and shores supporting the forms are to be inspected to verify that they are adequate in number and type, and that they are located in accordance with the approved plans. The dimensions and alignment of the forms are to be verified by the attending Surveyor. The measurements are to be within the allowable finished dimensional tolerances specified in the approved design.

Reinforcing steel, prestressing tendons, post-tensioning ducts, anchorages and any included steel are to be checked, as appropriate to the planned structure, for size, bending, spacing, location, firmness of installation, surface condition, vent locations, proper duct coupling, and duct capping.

3.9.3 Inspection of Batching, Mixing, and Placing Concrete

The production and placing of the concrete are to employ procedures which will provide a well-mixed and well-compacted concrete. Such procedures are also to limit segregation, loss of material, contamination, and premature initial set during all operations.

Mix components of each batch of concrete are to be measured by a method specified in the quality control program. The designer is to specify the allowable variation of mix component proportions, and the Fabricator is to record the actual proportions of each batch.

Testing during the production of concrete is to be carried out following the procedures specified in the quality control program. As a minimum, the following concrete qualities are to be measured by the Fabricator.

i) Consistency

ii) Air content

iii) Density or Specific Gravity

iv) Strength

Field testing of aggregate gradation, cleanliness, moisture content, and unit weight is to be performed by the Fabricator following standards and schedules specified in the quality control program. The frequency of testing is to be determined with the consideration of the uniformity of the supply source, volume of concreting, and variations of atmospheric conditions. Mix water is to be tested for purity following methods and schedules specified in the quality control program.

3.9.4 Inspections of Form Removal and Concrete Curing

The structure is to have sufficient strength to bear its own weight, construction loads and the anticipated environmental loads without undue deformations before forms and form supports are removed. The schedule of form removal is to be specified in the quality control program, giving due account to the loads and the anticipated strength.

Curing procedures for use on the structure are to be specified in the quality control program. When conditions at the construction site cause a deviation from these procedures, justification for these deviations is to be fully documented and included in the construction records.

Where the construction procedures require the submergence of recently placed concrete, special methods for protecting the concrete from the effects of salt water are to be specified in the quality control program. Generally, concrete is not to be submerged until 28 days after placing.

3.9.5 Inspection of Prestressing and Grouting

A schedule indicating the sequence and anticipated elongation and stress accompanying the tensioning of tendons is to be prepared. Any failures to achieve proper tensioning are to be immediately reported to the designer to obtain guidance on needed remedial actions.

Pre- or post-tensioning loads are to be determined by measuring both tendon elongation and tendon stress. These measurements are to be compared. In the case that the variation of measurements exceed the specified amount, the cause of the variation is to be determined and any necessary corrective actions are to be accomplished.

The grout mix is to conform to that specified in the design. The Fabricator is to keep records of the mix proportions and ambient conditions during grout mixing. Tests for grout viscosity, expansion and bleeding, compressive strength, and setting time are to be made by the Fabricator using methods and schedules specified in the quality control program. Employed procedures are to verify that ducts are completely filled.

Anchorages are to be inspected to verify that they are located and sized as specified in the design. Anchorages are also to be inspected to verify that they are provided with adequate cover to mitigate the effects of corrosion.

3.9.6 Inspection of Joints *(1 July 2020)*

Where required, leak testing of construction joints is to be carried out using procedures specified in the quality control program. When deciding which joints are to be inspected, consideration is to be given to the hydrostatic head on the subject joint during normal operation, the consequence of a leak at the subject joint, and the ease of repair once the Floating Offshore Wind Turbine is in service.

3.9.7 Inspection of Finished Concrete

The surface of the hardened concrete is to be inspected for cracks, honeycombing, pop-outs, spalling and other surface imperfections. When such defects are found, their extent is to be reported to the Surveyor and to the designer for guidance on any necessary repairs.

The structure is to be examined using a calibrated rebound hammer or a similar nondestructive testing device. Where the results of surface inspection, cylinder strength tests or nondestructive testing do not meet the design criteria, the designer is to be consulted regarding remedial actions to be taken.

The completed sections of the structure are to be checked for compliance with specified design tolerances for thickness, alignment, etc., and to the extent practicable, the location of reinforcing and prestressing steel and post-tensioning ducts. Variations from the tolerance limits are to be reported to the designer for evaluation and guidance on any necessary remedial actions.

3.11 Piping Systems

All piping installation and testing is to be in accordance with ABS-approved drawings and procedures. Welds are to be visually inspected and nondestructively tested, as required and to the satisfaction of the attending Surveyor. Upon completion of satisfactory installation, the piping system is to be proven tight by pressure testing in accordance with the applicable requirements in 7-1-4/41 of the *MOU Rules*. Where sections of pipes are hydrostatically tested at the fabrication shops, an onboard test is to be conducted to confirm proper installation and tightness of the flanged and/or welded connections.

3.13 Electrical Systems and Installations

All electrical wiring, equipment, and systems within the scope of classification are to be installed and tested in accordance with ABS-approved drawings and procedures. Proper support for all cables and suitable sealing of cable entries to equipment are to be verified. Upon completion of wire connections, the affected sections of the equipment and cabling are to be insulation-tested and proven in order. All grounding is also to be verified in order.

3.15 Instrumentation and Control Systems *(1 July 2020)*

All instrumentation and control systems within the scope of classification are to be installed and tested in accordance with ABS-approved drawings and procedures. All supports are to be verified. Upon completion, instrumentation and control systems are to be functionally tested and demonstrated to be in order.

3.17 Mechanical Equipment and Systems

All mechanical equipment and systems within the scope of classification is to be installed and tested in accordance with ABS-approved drawings and procedures, including the grounding of the equipment. Upon completion, mechanical equipment and systems are to be functionally tested and proven in order.

3.19 Fire and Safety Features

All fire and safety features are to be installed and tested in accordance with ABS-approved drawings and procedures and to the satisfaction of the attending Surveyor.

3.21 Stationkeeping System *(1 July 2020)*

Fabrication tests for the stationkeeping system components, such as anchors, chains, wires, shackles, etc. are to satisfy the requirements of the ABS *Rules for Materials and Welding (Part 2)* for the respective sizes of equipment. Compliance with the ABS *Guide for Certification of Offshore Mooring Chain* is also required. Requirement specific to synthetic fiber ropes is provided in the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*. In addition, it is to be confirmed that the stationkeeping system equipment is in compliance with the Owner's specification. Physical testing, including break, pull, dimensional and nondestructive testing, is required to be performed in accordance with the submitted specifications and to the satisfaction of the attending Surveyor

Back-up structure/foundations on the floating substructure are required to be surveyed in compliance with ABS approved drawings, in the presence of and to the satisfaction of the attending Surveyor. Proper fit-up, alignment and final weldments of hull foundations for mooring winches, fairleads and other stationkeeping system components are to be visually examined. Completed welds are to be examined using surface NDT (preferably Magnetic Particle Inspection) to the extent deemed necessary by the attending Surveyor.

5 Installation, Hook-up and Commissioning Surveys

5.1 Surveys During Installation and Hook-up *(1 July 2020)*

For the floating substructure and the stationkeeping system, detailed requirements for surveys during installation and hook-up are to be in accordance with applicable requirements in Part 7, Chapter 1 of the *FPI Rules*. In general, it is to include the following items:

- General description of the mooring system and the floating substructure
- Pre-installation verification procedures for the sea-bed condition and contingency procedures
- Pile/anchor and mooring line installation procedures
- Tensioning and proof load testing procedures of the anchor piles or anchor-chain system
- Hook-up of the anchor chain system to the floating substructure
- Final field erection and leveling
- Pre-tensioning of mooring system
- Hook-up of piping, electrical, instrumentation and mechanical equipment

Where the RNA and tower are not within the scope of classification, the valid type certificate of the RNA and the tower are to be examined by the attending Surveyors. The installation of the RNA and tower and the hook-up of the power cable system are not to damage the interface structure to the floating substructure.

Where the RNA and the tower are within the scope of classification, the Surveyor is to witness the installation of at least one (1) RNA and one (1) tower per each wind turbine type. Where there are more than fifty (50) RNAs and towers of the same type, at least one (1) additional RNA and tower installation per every fifty (50) turbines of the same type is to be witnessed by the Surveyor. The selection of the RNA and the tower to be witnessed is to reflect having Surveys at the start and end of installation periods and the rate of installation within an installation period of the RNA and tower.

The attending Surveyor is to verify that the RNA and the tower to be installed are in compliance with relevant design documents for the Floating Offshore Wind Turbine. Deviations from approved design documents and plans or any incidents such as damage or overstress to the floating substructure or the stationkeeping system during the installation may require re-submittal of supporting documentation to provide an assessment of the significance of deviation and any necessary remedial actions to be taken. Any anomalies noted during the installation of the tower (when classed), floating substructure, and mooring are to be recorded in the ISIP for reference during later surveys.

5.3 Commissioning Surveys *(1 July 2020)*

The commissioning date will be the date on which the Surveyor issues the Interim Classification Certificate for the Floating Offshore Wind Turbine . Commissioning of all ABS Rule/Guide-required systems is to be verified by the attending ABS Surveyor. The commissioning is to be in accordance with the approved step-by-step commissioning procedures. The Surveyor is to be permitted access to critical/ hold points to verify that the procedures are satisfactorily accomplished. The Surveyor is to observe the Floating Offshore Wind Turbine operating under various capacities and conditions.

Where the RNAs are within the scope of classification, the Surveyor is to witness the commissioning of at least one (1) RNA per each wind turbine type. Where there are more than fifty (50) RNAs of the same type, the commissioning of at least one (1) additional RNA per every fifty (50) turbines of the same type is to be witnessed by the Surveyor. The selection of RNA commissioning to be witnessed is to reflect having Surveys at the start and end of RNA commissioning periods. Approved turbine RNA operations including emergency procedures are to be verified to the extent deemed necessary by the attending Surveyor. Overall performances of the turbine RNA are to be verified for compliance with the design parameters used in the design of the Floating Offshore Wind Turbine. Records of all these performances are to be maintained and made available to ABS.

5.5 Personnel Safety *(1 July 2020)*

Verification of personnel safety features which include checks of operational readiness of all lifesaving, fire detection and firefighting equipment, emergency shutdown systems, unobstructed escape routes, lighting and establishment of communication procedures are to be taken during commissioning and are required to be verified by the attending Surveyor.

CHAPTER 11
Surveys

SECTION 2
Surveys After Installation and Commissioning

1 General *(1 July 2020)*

This Section pertains to periodical surveys after installation and commissioning for the maintenance of classification of the Floating Offshore Wind Turbine Turbine.

For the RNA and the tower, the survey scope includes the following two situations:

- The optional **RNA** notation is requested by the Owner. The RNA and tower including its end connections are type approved by ABS and are within the scope of classification and survey.
- The optional **RNA** notation is not requested by the Owner. However, the tower and its connection to the RNA and/or to the substructure are not included in the wind turbine type certificate. In this scenario, the tower and its connection are within the scope of classification and survey. The RNA with a wind turbine type certificate is not within the scope of classification.

1.1 Notification and Availability for Survey *(1 July 2020)*

The Surveyor is to be provided access to the classed Floating Offshore Wind Turbine at all reasonable times. The Owners or their representatives are to notify the Surveyor on all occasions when the Floating Offshore Wind Turbine can be examined on site.

The Surveyor is to undertake all surveys on the classed Floating Offshore Wind Turbine upon request, with adequate notification, of the Owners or their representatives and are to report thereon to ABS. Should the Surveyor find occasion during any survey to recommend repairs or further examination, notification is to be given immediately to the Owners or their representatives in order that appropriate action may be taken. The Surveyor is to avail themselves of every convenient opportunity for performing periodical surveys in conjunction with surveys of damages and repairs in order to avoid duplication of work. Also see 1-1-8/3 of the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

3 In-Service Inspection Program (ISIP) *(1 July 2020)*

The ISIP as required by 1-1/13.3 is to cover all surveys for the design life of the Floating Offshore Wind Turbine. The In-Service Inspection Program (ISIP) is a comprehensive program that outlines the procedures to be followed and the inspection frequency of a Floating Offshore Wind Turbine. All Floating Offshore Wind Turbines are to be surveyed in accordance with an ABS approved ISIP plan. For further details, see Section 7-2-3 of the *FPI Rules*.

Structure Critical Inspection Points (SCIPs, see 1-1/17.3.30) are to be included in the ISIP. The ISIP plan is also to include:

i) A copy of the ABS review letter agreeing to the defined Structural Critical Inspection Points

ii) Structural Wastage allowances

iii) Details of access to structures and/or remote inspection techniques employed

Depending on the type, configuration and structural design of a floating substructure, the reference can be made to 7-2-3/3.5 of the *FPI Rules* for typical structural areas and joints that are considered to be critical inspection areas. In addition, intersection structures of the floating substructure supporting the tower are considered to be Special Application Structures. Where the tower and its interface structures to the RNA are within the scope of classification, they are considered to be Special Application Structures.

For Floating Offshore Wind Turbines surveyed under Continuous Survey, the due dates shown in ABS Survey Status are to be per the "ISIP Master Inspection Plan". An outline of the installation inspection schedule and frequency of examination for all the hull structure and mooring system components are to be included in the ISIP plan. In general, this outline may be called the "ISIP Master Inspection Plan" and cover the entire life-cycle of the field. For further requirements of the ISIP, refer to Section 7-2-3 of the *FPI Rules*, where applicable.

Inspection requirements for the UWILD are to be included in the approved In-Service Inspection Program (ISIP). The ISIP is also to discuss the means of access for each compartment, detailing how the periodic examinations will be completed, including general examination and access for close up examinations of Structural Critical Inspection Points. Proposed alternative techniques of inspection should be detailed in the ISIP.

The Attending Surveyor is to review the ISIP for progression of the Special Periodical Survey and for Floating Offshore Wind Turbines under Continuous Survey at each Annual Survey. This review is to verify that the ISIP is being maintained per the approved schedule and any adjustments are to take into consideration before the due date of the Special Survey.

An ISIP is mandatory for ABS class surveys on all Floating Offshore Wind Turbines.

As an alternative to a time-based inspection program, a Risk Based Inspection (RBI) plan approved in accordance with Section 11-3 of this Guide may be considered so long as it includes all components of the ISIP. The RBI plan is to be submitted and agreed by ABS.

5 Surveys

5.1 Annual Survey *(1 July 2020)*

An Annual Survey of the Floating Offshore Wind Turbine is to be carried out within three (3) months before or after each annual anniversary date of the crediting of the previous Special Periodical Survey or original construction date.

Where the Surveyor is engaged in the survey of a group of structures of similar design and location, and where requested by the Owner, special consideration will be given to the timing of Annual Surveys and Special Periodical Surveys such that all periodical survey due dates can be harmonized.

For the Floating Offshore Wind Turbine on Continuous Survey, all Continuous Survey requirements for those parts (items) due are generally to be completed each year. The Annual Survey will not be credited and the Certificate of Classification will not be endorsed unless Continuous Survey items which are due or overdue at the time of the Annual Survey are either completed or granted an extension.

For further requirements of the Annual Survey, refer to the *MOU Rules*, where applicable, as follows:

i) 7-2-4/1 for the floating substructure and, where applicable, the tower

a. All units over 5 years of age are to have the continued effectiveness of corrosion control methods in uncoated ballast tanks verified.

ii) 7-2-4/3 for machinery, equipment and systems and, where applicable, the RNA

The Annual Survey of the stationkeeping systems is to follow the applicable requirements in Section 7-2-4 of the *FPI Rules*.

For column tanks when the ballast is permanent and also not coated, confirmation of corrosion condition of test coupon is to be made during Annual Survey.

For the Annual Survey of a wind farm with a group of wind turbines having a similar design, the group of wind turbines can be considered as a set and examined in accordance with the approved ISIP.

5.3 Special Periodical Survey *(1 July 2020)*

A Special Periodical Survey of the Floating Offshore Wind Turbine is to be carried out within five (5) years of the initial Classification Survey, and at five-year intervals thereafter.

The Special Periodical Survey may be commenced at the fourth Annual Survey and be continued with completion by the fifth anniversary date. Where the Special Periodical Survey is commenced prior to the fourth Annual Survey, the entire survey is to be completed within 15 months if such work is to be credited to the Special Periodical Survey.

A Special Periodical Survey will be credited as of the completion date of the survey but not later than five years from date of build or from the date recorded for the previous Special Periodical Survey. If the Special Periodical Survey is completed within three (3) months prior to the due date, the Special Periodical Survey will be credited to agree with the effective due date.

Special consideration may be given to Special Periodical Survey requirements in unusual cases. Consideration may be given for extensions of Rule-required Special Periodical Surveys under extreme circumstances.

The Special Periodical Survey requirements are in addition to the Annual Survey requirements stated in 11-2/5.1 of this Guide.

For further requirements of the Special Periodical Survey, refer to the *MOU Rules*, where applicable, as follows:

i) 7-2-5/1 and 7-2-5/5 for the floating substructure and, where applicable, the tower

ii) General Visual Inspection (GVI), Close Visual Inspections (CVI) and Nondestructive Testing (NDT) requirements detailed in the In-Service Inspection Program (ISIP) are to be followed.

iii) Requirements of 7-2-5/5.3.6 of the *MOU Rules* (Lightship Displacement) are not applicable. However, units are to be verified floating at the expected draft.

iv) 7-2-5/9 through 7-2-5/13 for machinery, equipment and systems and, where applicable, the RNA

The Special Periodical Survey of the stationkeeping systems is to follow the applicable requirements in Section 7-2-6 of the *FPI Rules*.

For permanent ballast tanks, internal examination requirements will be specially considered for tanks used exclusively for permanent ballast which are fitted with an effective means of corrosion control in accordance with 7-A1-4/25 of the ABS *Rules for Survey After Construction (Part 7)*.

For Special Periodical Surveys of an offshore wind farm with a group of wind turbines having a similar design, the group of wind turbines can be surveyed as a set, in accordance with the ISIP. Continuous Surveys can be applied (see 11-2/5.7).

5.5 Underwater Inspection in Lieu of Drydocking Survey (UWILD) *(1 July 2020)*

UWILD Surveys are to be carried out by a company approved by ABS as an External Specialist. The Survey is to be completed once in any five-year period and in association with Special Periodical Survey. Consideration may be given for extensions of the UWILD Survey due dates under special circumstances.

An examination of the underwater parts of each Floating Offshore Wind Turbine, including floating substructure, corrosion protection system, power cable system (if classed), and mooring system are to be made at UWILD Survey. Prior to examination, all power cables, mooring, and anchoring attachments are to be cleaned, including all openings to the sea, if any. Cables and mooring lines, including connecting hardware, are to be examined over the full length from the lowest exposed point at the seabed to the connection point at the Floating Offshore Wind Turbine.

Inspection requirements for the UWILD are to be included in the approved In-Service Inspection Program (ISIP). Any underwater GVI/CVI or NDT requirements included in the In-Service Inspection Program (ISIP) are to be followed.

For further requirements of the UWILD Surveys, refer to Section 7-2-6 of the *FPI Rules*, where applicable.

For the UWILD Surveys for an offshore wind farm with a group of wind turbines of similar design, the group of wind turbines can be surveyed as a set, in accordance with the ISIP. A Continuous Survey can be applied (see 11-2/5.7).

5.7 Continuous Survey Program

At request of the Owner, and upon approval of the proposed arrangements, a system of Continuous Surveys may be undertaken, whereby the Special Periodical Survey requirements are carried out in regular rotation to complete all of the requirements of the particular Special Periodical Survey within a five-year period. The proposed arrangements are to provide for survey of approximately 20% of the total number of survey items during each year of the five-year period. Reasonable alternative arrangements may be considered.

Each part (item) surveyed becomes due again for survey approximately five (5) years from the date of the survey and the due parts (items) are generally to be completed each year. For Continuous Surveys, a suitable notation will be entered in the *Record* and the date of the completion of the cycle published.

ABS may withdraw its approval for Continuous Survey if the Surveyor's recommendations are not complied with.

5.9 In-line Surveys and Timing of Surveys *(1 July 2020)*

All items required to undergo the Special Periodical Survey are to be carried out at the same time and interval in order that they are recorded with the same crediting date. In cases where damage has involved extensive repairs and examination, the survey may, where approved by ABS, be accepted as equivalent to the Special Periodical Survey.

Surveys are to be completed within three (3) months of their due dates, unless extended by agreement with ABS. Surveys carried out within this three-month window period will be credited and due at the same anniversary date in subsequent cycle. When so desired by the Owner, any part of the Floating Offshore Wind Turbine may be offered for survey prior to the three-month window and the survey will be credited as of the date it has been surveyed.

7 Survey Report File *(1 July 2020)*

All survey reports and records of all abnormalities found are to be compiled into the Survey Report File that is to be kept by the Owner at all times for reference during any survey. The records to be kept include, but are not limited to, the following:

i) Approved In-Service Inspection Program (ISIP), as required by 11-2/3

ii) The updated status records of all class surveys

iii) The records of all abnormalities found that are to include all videos and photographic records

iv) The records of all repairs performed on any abnormalities found and any further repetitive abnormalities found subsequent to the repairs

v) Records of all corrosion protection system maintenance, including records of all cathodic potential readings taken, records of depletion of all sacrificial anodes, anode replacement, impressed current maintenance records, such as voltage and current demands of the system, coating breaks and the monitoring records of the steel material wastage in way of the coating break areas

vi) All classification reports pertaining to the Floating Offshore Wind Turbine

vii) Reports of thickness measurements of the floating substructure

viii) Reports of all NDT and thickness measurements performed

ix) Underwater examination reports including examination of hull and mooring

x) Mooring integrity documentation

9 Incomplete Surveys *(1 July 2020)*

When a survey is only partially completed, the Surveyor is to report immediately upon the work completed so that the Owners and ABS may be advised of the parts still to be surveyed.

11 Alterations *(1 July 2020)*

No alterations that affect or may affect classification are to be made to the classed Floating Offshore Wind Turbine, unless plans of the proposed alterations are submitted and approved by ABS before the work of alterations is commenced. Such work, when approved, is to be performed to the satisfaction of the Surveyor. Nothing contained in this Section or in a rule or regulation of any government or other administration or the issuance of any report or certificate pursuant to this Section or such a rule or regulation is to be deemed to enlarge upon the representations expressed in 1-1-1 of the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*. The issuance and use of any such reports or certificates are to be governed in all respects by 1-1-1 of the ABS *Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

13 Damage and Repairs *(1 July 2020)*

If the Floating Offshore Wind Turbine that has been classed suffers any damage to structure, machinery, piping, equipment, mooring, etc. which may affect classification, ABS is to be notified and the damage examined by the Surveyor. Details of intended repairs are to be submitted for approval, and the work is to be carried out to the satisfaction of the attending Surveyor.

When a piece of machinery, piping, equipment, mooring, etc. suffers a premature or unexpected failure and is subsequently repaired or replaced without Surveyor attendance, details of the failure, including damaged parts, where practicable, are to be retained onboard for examination by the Surveyor during the next scheduled visit. Alternatively, the part or parts may be landed ashore for further examination and testing, as required.

If failures noted in the paragraph above are deemed to be a result of inadequate or inappropriate maintenance, the maintenance plan and the survey and inspection plan are to be amended and resubmitted for approval.

15 Welding and Replacement of Materials

15.1 Ordinary and Higher Strength Structural Steels

Welding or other fabrication performed on the structural steels is to follow the requirements of Chapter 2.

15.3 Special Materials

Welding or other fabrication performed on other steels of special characteristics or repairs or renewals of such steel or adjacent to such steel is to be accomplished with procedures approved for the special materials involved. The procedures are to take into account the information provided in Chapter 2.

15.5 Substitutions and Alterations

Substitution of steel differing from that originally installed, alteration of original structural configuration, or change from bolted to welded joint is not to be made without approval by ABS.

17 Inspection for Concrete Structures *(1 July 2020)*

When there are no requirements provided in the Guide, inspection for concrete structures is to be based on ISO 19903, Chapter 14.

19 Preparations for Safe Execution of Surveys *(1 July 2020)*

The Owner is to provide the necessary facilities for a safe execution of the surveys to be carried out by the attending Surveyor. Refer to 7-2-1/19 of the *MOU Rules* for the requirements for preparations for safe execution of surveys.

21 Maintenance of Rotor-Nacelle Assembly (RNA) *(1 July 2020)*

The Owner is to submit an annual report for review by the attending Surveyor attesting to the following:

i) Maintenance has been carried out by authorized and qualified personnel in accordance with the maintenance manual.

ii) The control settings have been checked with regard to conformance with the limiting values specified in design documentation of the classed Floating Offshore Wind Turbine.

iii) All repair, modification and replacement have not altered values of RNA parameters specified in design documentation of the classed Floating Offshore Wind Turbine.

23 Survey for Extension of Use *(1 July 2020)*

When an existing classed Floating Offshore Wind Turbine is to remain in service at the same location for an extended period of time beyond its original design life, it is to be subject to inspections and testing, as deemed necessary, to determine its condition. The extent of the inspections and testing will depend on the completeness of the existing survey documents and inspection records. ABS will review and verify maintenance manual, logs and records. Any alterations, repairs, or installation of equipment since installation are to be included in the records.

Those survey requirements in 11-2/5.3 for the Special Periodical Survey are to be included in the survey for extension of use. The surveys generally cover examination of splash zone, inspection of above water and underwater structural members and welds for damages and deteriorations, inspection of the stationkeeping system, examination and measurements of corrosion protection systems and marine growth, sea floor condition survey, examination of secondary structural attachments such export electrical cable support structures, service decks, etc. Special attention is to be given to the following critical areas.

i) Areas of high stress

ii) Areas of low fatigue life

iii) Damage incurred during installation or while in service

iv) Repairs or modifications made while in service

v) Abnormalities found during previous surveys

An inspection report of the findings is to be submitted to ABS for review and evaluation of the condition of the Floating Offshore Wind Turbine.

The need for more frequent future periodical surveys is to be determined based on the calculated remaining fatigue life and the expected extension of service life.

25 Relocation of Existing Installations *(1 July 2020)*

An existing Floating Offshore Wind Turbine that is classed for a specified location requires special consideration when relocation to a new site is proposed. The Owner is to advise ABS of the proposal to change locations, addressing removal, transportation, and re-installation aspects of the change. Survey requirements described in Section 11-1 and 11-2/23, wherever applicable, are to be complied with in addition to engineering analyses required to justify the integrity of the installation for the design life at the new location.

27 Certification on Behalf of Coastal States

When ABS is authorized to perform surveys on behalf of a coastal State or a governmental authority, and when requested by the Owner, items as specified by the coastal State, the governmental authority or Owner will be surveyed. Reports indicating the results of such surveys will be issued accordingly. Where the periodicity and types of surveys on behalf of a coastal State or a governmental authority differ from those required by the applicable portions of this Section, coastal State or governmental authority's requirements take precedence.

CHAPTER 11
Surveys

SECTION 3
Risk-based Surveys for Maintenance of Class

1 General *(1 July 2020)*

Risk-Based Inspection (RBI) provides an alternative means to Classification rule-based or calendar-based inspection regimes. A properly developed risk-based inspection plan or reliability centered maintenance plan may be credited as satisfying requirements of Surveys for Maintenance of Class for the Floating Offshore Wind Turbine. The plan is to be developed in accordance with the ABS *Guide for Risk-Based Inspection for Floating Offshore Installations* or the ABS *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques*.

1.1 Applicability *(1 July 2020)*

While this Section provides risk-based survey requirements as an alternative for maintenance of Class, the Sections on the classification process contained in this Guide remain applicable. Where no specific references or guidance are given in this Section, the relevant requirements of conventional Rules/Guides remain valid.

1.2 Survey Periods *(1 July 2020)*

Because of the diverse nature and purposes of Floating Offshore Wind Turbines and the varied contents of inspection plans likely to be developed as part of an Owner's risk-based approach to Classification, the survey schedule of individual items will be established by the RBI plan. The overall plan will include Annual Surveys and Special Surveys.

3 Certification on Behalf of Coastal States *(1 July 2020)*

The application of the Guides referenced in 11-3/1 does not cover any statutory survey requirements that may apply to the Floating Offshore Wind Turbine being considered. Only when the coastal States and/or other governmental authorities accept and authorize ABS for certification based on risk-based inspection techniques, ABS will carry out such surveys, as authorized. The Owner is to confirm that in developing the inspection plan, due consideration is given to applicable requirements external to ABS. If the coastal States and/or other governmental authorities do not accept a risk-based approach, surveys will be carried out in a conventional, prescriptive manner in compliance with Section 11-2.

APPENDIX 1

Wind Spectra and Coherence Functions

CONTENTS

APPENDIX 1
Wind Spectra and Coherence Functions

SECTION 1
Wind Spectra and Coherence Functions *(1 July 2020)*

1 Kaimal Wind Spectrum and Exponential Coherence Model

A modified version of the Kaimal wind spectrum is provided in IEC 61400-1 (2019). The power spectral densities for the wind fluctuations in three dimensions are given as follows:

$$\frac{f \cdot S_k(f)}{\sigma_k^2} = \frac{4fL_k/V_{hub}}{(1 + 6fL_k/V_{hub})^{5/3}}$$

where

$S_k(f)$	=	spectral energy density at frequency f, in m^{2}s^{-2}/Hz (ft^{2}s^{-2}/Hz)
f	=	frequency, in Hz
k	=	index referring to the direction of wind speed component (i.e., 1 = longitudinal, 2 = lateral, and 3 = upward, as depicted in 3-2/Figure 1)
σ_k	=	standard deviation of turbulent wind speed component (see A1-1/Table 1)
	=	$\left[\int_0^\infty S_k(f)df\right]^{0.5}$
L_k	=	integral parameter of turbulent wind speed component (see A1-1/Table 1)

TABLE 1
Spectral Parameters for the Kaimal Model

	Wind Speed Direction		
	k=1 (longitudinal)	***k=2 (lateral)***	***k=3 (upward)***
Standard Deviation (σ_k)	σ_1	$0.8\sigma_1$	$0.5\sigma_1$
Integral Scale (L_k)	$8.1\Lambda_1$	$2.7\Lambda_1$	$0.66\Lambda_1$

Note:

σ_1 = standard deviation of longitudinal turbulent wind speed

Λ_1 = scale parameter of the turbulence as specified in 3-2/11.5

Along with the Kaimal spectrum, an exponential coherence model is provided in IEC 61400-1 (2019) to account for the spatial correlation of the longitudinal wind speed:

$$Coh(r,f) = \exp\left[-12\sqrt{(f\cdot r/V_{hub})^2 + (0.12\cdot r/L_c)^2}\right]$$

where

$Coh(r,f)$	=	coherence function at frequency f
f	=	frequency, in Hz
r	=	magnitude of the projection of the separation vector between the two points on to a plane normal to the average wind direction, in m (ft)
V_{hub}	=	10-minute mean wind speed at hub height, in m/s (ft/s)
L_c	=	coherence scale parameter, in m (ft)
	=	$8.1\Lambda_1$, where Λ_1 is specified in 3-2/11.5

3 NPD (Frøya) Wind Spectrum and Coherence Model

For the extratropical storm wind, the NPD (Frøya) wind spectrum in conjunction with the two-point coherence function recommended by API RP 2MET (2019) may be applied. Details can be found in Annex A7.4.2 of API RP 2MET (2019).

3.1 Wind Spectrum

The following wind spectrum is defined for the energy density of the longitudinal wind speed fluctuations:

$$S(f) = \frac{320\phi^2\left(\frac{U_0}{10\phi}\right)^2\left(\frac{z}{10\phi}\right)^{0.45}}{\left(1+\tilde{f}^n\right)^{(5/3n)}}$$

$$\tilde{f} = 172f\left(\frac{z}{10\phi}\right)^{2/3}\left(\frac{U_0}{10\phi}\right)^{-0.75}$$

where

$S(f)$	=	spectral energy density at frequency f, in m^2s^{-2}/Hz (ft^2s^{-2}/Hz)
f	=	frequency, in Hz
U_0	=	1-hour mean wind speed at 10 m (32.8 ft) above the SWL, in m/s (ft/s)
n	=	0.468
z	=	height above the SWL, in m (ft)
ϕ	=	unit conversion factor, (dimensionless)
	=	1 when using SI units (m, m/s)
	=	3.28 when using US Customary units (ft, ft/s)

3.2 Spatial Coherence

The squared correlation between the spectral energy densities $S(f)$ of the longitudinal wind speed fluctuations between two points (x_j, y_j, z_j), $j = 1, 2$, in space is described by the two-point coherence function as follows:

$$Coh(f) = \exp\left\{-\frac{1}{U_0/\phi} \cdot \left[\sum_{i=1}^{3} A_i^2\right]^{\frac{1}{2}}\right\}$$

$$A_i = \alpha_i f^{r_i}\left(\frac{\Delta_i}{\phi}\right)^{q_i}\left(\frac{\sqrt{z_1 z_2}}{10\phi}\right)^{-p_i}$$

where the coefficients α_i, p_i, q_i, r_i and the distances Δ_i are specified in A1-1/Table 2, and

$Coh(f)$	=	coherence function at frequency f
f	=	frequency, in Hz
U_0	=	1-hour mean wind speed at 10 m (32.8 ft) above the SWL, in m/s (ft/s)
(x_j, y_j, z_j)	=	spatial coordinates of two points (j = 1, 2) where xj is in the longitudinal (along wind) direction, y_j is in the lateral (across wind) direction and z_j is the height above the SWL in the upward direction, in m (ft)
ϕ	=	unit conversion factor, (dimensionless)
	=	1 when using SI units (m, m/s)
	=	3.28 when using US Customary units (ft, ft/s)

TABLE 2
Coefficients and Distances for the Three-dimensional Coherence Function

I	Δ_i	q_i	p_i	r_i	α_i
1	$\lvert x_2 - x_1 \rvert$	1.00	0.4	0.92	2.9
2	$\lvert y_2 - y_1 \rvert$	1.00	0.4	0.92	45.0
3	$\lvert z_2 - z_1 \rvert$	1.25	0.5	0.85	13.0

5 Tropical Cyclone Wind Spectrum

For tropical storm wind, the following wind speed spectrum for the energy density of the longitudinal wind speed fluctuations is recommended by API RP 2MET (2019):

$$S(f,z) = \frac{4\, I_u^2\, U_{w,1h}(z)\, L_{u,x}(z)}{\left[1 + 70.8\left(f\, L_{u,x}(z)/U_{w,1h}(z)\right)^2\right]^{5/6}}$$

where

$S(f,z)$	=	spectral energy density at frequency f, and height z , in m^2s^{-2}/Hz (ft^2s^{-2}/Hz)
f	=	frequency, in Hz
z	=	height above the SWL, in m (ft)
$U_{w,1h}(z)$	=	1-hour average wind speed at a height z above the MSL, in m/s (ft/s)
$I_u(z)$	=	turbulence intensity at the height z above the MSL (see A2-1/5), (dimensionless)
$L_{u,x}(z)$	=	integral length scale at the height z above the MSL, in m (ft)

$$L_{u,x}(z) = \frac{50\phi\left(\frac{z}{\phi}\right)^{0.35}}{\left(\frac{z_0}{\phi}\right)^{0.063}}$$

z_0 = surface roughness length for tropical cyclone winds (see A2-1/3), in m (ft)

ϕ = unit conversion factor, (dimensionless)

= 1 when using SI units (m, m/s)

= 3.28 when using US Customary units (ft, ft/s)

APPENDIX 2

Tropical Cyclone Wind Speed Profile, Standard Deviation, Turbulence Intensity and Gust Factor

CONTENTS

APPENDIX 2

Tropical Cyclone Wind Speed Profile, Standard Deviation, Turbulence Intensity and Gust Factor

SECTION 1

Tropical Cyclone Wind Speed Profile, Standard Deviation, Turbulence Intensity and Gust Factor *(1 July 2020)*

1 Introduction

Extensive dropsonde measurements of major tropical cyclones in the Gulf of Mexico indicate that the tropical cyclone wind speed profile is on average steeper than the exponential wind speed profile specified in IEC 61400-1 for Extreme Wind Speed Model (EWM, see 4-2/11.1 of this Guide). The measured wind profiles are also steeper than those NPD (Frøya) wind model originally developed based on the North Sea data.

Tropical cyclone wind data collected on the platforms in the Gulf of Mexico indicate that the turbulence intensity is insensitive to the change of mean wind speed. The average observed value of turbulence intensity is slightly smaller than 0.11 as defined in IEC 61400-1 for the Extreme Wind Speed Model (EWM, see 4-2/11.1 of this Guide) but could differ noticeably from the value calculated with the NPD (Frøya) wind model. In addition, the measured gust factors of tropical cyclone winds are found to be less sensitive to the change of mean wind speed in comparison to the calculated gust factors in the NPD (Frøya) wind model.

The formulation of the wind speed profile, wind speed standard deviation, turbulence intensity and gust factors presented in this Appendix is found to provide reasonably good representations of the measurements of tropical cyclone wind in the Gulf of Mexico. In absence of site data, the formulation in this Appendix may be used to model tropical cyclone (also known as hurricane or typhoon) wind conditions over the open ocean.

2 Tropical Cyclone Wind Speed Profile

Tropical cyclone wind boundary layers within approximately 200 m above the sea surface of the open ocean can be represented by an equilibrium form of the logarithmic boundary layer profile under neutral stability conditions, i.e.:

$$V_{1\mathrm{hr}}(z) = \frac{u_*}{k}\ln\left(\frac{z}{z_0}\right)$$

where

$V_{1hr}(z)$	=	one hour mean longitudinal wind speed at the height z above the sea surface, in m/s (ft/s)
u_*	=	friction velocity, in m/s (ft/s)
z	=	height above the sea surface, in m (ft)
z_0	=	surface roughness length, in m (ft)
k	=	von Karman constant, (dimensionless)
	=	0.4

For mean wind speed $V_{1hr}(z_{ref})$ lower than approximately 27 m/s (52.5 knots), the surface roughness length z_0 over the open ocean may be calculated using the Charnock equation:

$$z_0 = \frac{\alpha u_*^2}{g} = \frac{\alpha}{g}\left[\frac{kV_{1\text{hr}}(z)}{\ln\left(\frac{z}{z_0}\right)}\right]^2$$

where

α	=	0.011, as suggested in IEC 61400-3, for the open ocean
z_{ref}	=	10 m (33 ft) reference height above the sea surface, in m (ft)
$V_{1\text{hr}}(z_{ref})$	=	1-hour mean wind speed at the reference height z_{ref} above the sea surface, in m/s (ft/s)
g	=	acceleration of gravity, in m/s^2 (ft/s^2)

Alternatively, the surface roughness length z_0 over the open ocean can be determined from the boundary layer wind profile and expressed in terms of the surface drag coefficient $C_d(z_{ref})$ at the reference height z_{ref} = 10 m (33 ft) through the surface shear stress $\tau_0 = \rho u_*^2 = \rho C_d(z_{ref}) V_{1\text{hr}}^2(z_{ref})$, where ρ is the air density and $C_d(z_{ref})$ is the surface drag coefficient at the reference height z_{ref} above the sea surface, such that:

$$u_* = \sqrt{C_d(z_{ref})}V_{1\text{hr}}(z_{ref})$$

$$z_0 = 10 \times \exp\left(-\frac{k}{\sqrt{C_d(z_{ref})}}\right)$$

where the surface drag coefficient $C_d(z_{ref})$ may be calculated by:

$$C_d(z_{ref}) = \left[0.49 + 0.065V_{1\text{hr}}(z_{ref})\right] \times 10^{-3}$$

The values of $C_d(z_{ref})$ and z_0 determined by the equations given above will increase along with the mean wind speed. However, it is found that the $C_d(z_{ref})$ levels off for the wind speed $V_{1hr}(z_{ref})$ exceeding approximately 22 m/s ~ 30 m/s (43.8 knots ~ 58.3 knots) and may even decrease slightly at very high wind speeds, probably due to wave breaking and increasingly frothy sea surface. The maximum $C_d(z_{ref})$ over the open ocean is estimated in the range of 0.0019 ~ 0.0025 depending on the size of the tropical cyclone and the maximum wind speed. As a results, the surface roughness length z_0 over the open ocean is approximately in the range of 0.001 m ~ 0.0034 m (0.0033 ft ~ 0.011 ft). For typical tropical cyclones over the open ocean, the following limiting value should be applied:

$$C_d(z_{ref}) \leq 0.0023$$

5 Standard Deviation of Tropical Cyclone Wind Speed and Turbulence Intensity

The standard deviation of instantaneous tropical cyclone wind speed within one hour time duration is determined using the formulation suggested in ESDU 83045 *Strong Winds in the Atmospheric Boundary Layer, Part 2: Discrete Gust Speeds* (2002), in conjunction with the friction velocity u_* and the surface roughness length z_0 determined in accordance with this Appendix (see A2-1/3).

$$\sigma_u(z) = \frac{7.5\eta\left[0.538 + 0.09\ln\left(\frac{z}{z_0}\right)\right]^{\eta^{16}}}{1 + 0.156\ln\left(\frac{u_*}{fz_0}\right)} u_*$$

where

$\sigma_u(z)$	=	standard deviation of the instantaneous longitudinal wind speed at the height z above the sea surface, in m/s (ft/s)
η	=	scaling parameter, (dimensionless)
	=	$1 - \frac{6fz}{u_*}$
f	=	Coriolis parameter, in rad/s
	=	$1.458 \times 10^{-4} \sin\phi$
ϕ	=	local angle of latitude, in degrees

The turbulence intensity, defined as the standard deviation of the wind speed divided by the mean wind speed at the same height, is given by:

$$I_u(z) = \frac{\sigma_u(z)}{V_{1hr}(z)} = \frac{\sigma_u(z)}{u_*}\frac{u_*}{V_{1hr}(z)}$$

$$= \frac{7.5\eta\left[0.538 + 0.09\ln\left(\frac{z}{z_0}\right)\right]^{\eta^{16}}}{1 + 0.156\ln\left(\frac{u_*}{fz_0}\right)} \frac{k}{\ln\left(\frac{z}{z_0}\right)}$$

where the frication velocity u_* can be determined either by the surface wind profile, or the relation derived from surface shear stress.

The turbulence intensity $I_u(z)$ is weakly dependent on the mean wind speed and, for strong winds, can be considered approximately independent of the mean wind speed.

7 Tropical Cyclone Wind Gust Factor

The longitudinal gust wind speed, $V_\tau(z)$, which represents the maximum value of longitudinal wind speed occurring in a given observation period averaged over a shorter period, is related to the mean longitudinal wind speed in the same observation period through the gust factor as defined below:

$$V_\tau(z) = G(z, \tau, T_0)V_{T_0}(z)$$

$$= [1 + g(z, \tau, T_0)I_u(z)]V_{T_0}(z)$$

where

$V_\tau(z)$	=	longitudinal gust wind speed at the height z above the sea surface with averaging time duration of τ, in m/s (ft/s)
$V_{T_0}(z)$	=	mean longitudinal wind speed at the height z above the sea surface in a given reference observation time period T_0, in m/s (ft/s)
$G(z, \tau, T_0)$	=	gust factor, (dimensionless)
$g(z, \tau, T_0)$	=	peak factor, (dimensionless)
z	=	height above the sea surface, in m (ft)
τ	=	gust averaging time duration, in seconds
T_0	=	reference observation time duration ($T_0 > \tau$), in seconds
$I_u(z)$	=	turbulence intensity at the height z above the sea surface, (dimensionless)

For the one hour observation time period, the peak factor can be approximately calculated by:

$$g(z, \tau, T_0 = 3600\mathrm{s}) = \frac{\sigma_u(z, \tau, T_0 = 3600\mathrm{s})}{\sigma_u(z)}\left[\sqrt{2\ln(3600\upsilon)} + \frac{0.577}{\sqrt{2\ln(3600\upsilon)}}\right]$$

$$\frac{\sigma_u(z, \tau, T_0 = 3600\mathrm{s})}{\sigma_u(z)} = 1 - 0.193\left(\frac{T_u}{\tau} + 0.1\right)^{-0.68}$$

where

$\sigma_u(z, \tau, T_0)$	=	standard deviation of the wind speed at the height z above the sea surface with averaging time duration of τ observed during a period of T_0, in m/s (ft/s)
$\sigma_u(z)$	=	standard deviation of the instantaneous wind speed at the height z above the sea surface, in m/s (ft/s)
υ	=	zero up-crossing frequency of wind speed, in Hz
	=	$\left[0.007 + 0.213(T_u/\tau)^{0.654}\right]/T_u$
T_u	=	longitudinal integral length time scale, in seconds
	=	$3.12z^{0.2}$

The gust factor associated with one hour reference time period is relate to the peak factor through:

$$G(z, \tau, T_0 = 3600\mathrm{s}) = 1 - g(z, \tau, T_0 = 3600\mathrm{s})I_u(z)$$

As an example, the maximum 10-mintue mean wind speed observed in a one hour time duration can be obtained by:

$$V_{10\mathrm{min}}(z) = G(z, \tau = 600\mathrm{s}, T_0 = 3600\mathrm{s})V_{1\mathrm{hr}}(z)$$

For $z = z_{ref}$ = 10 m (33 ft) above the sea surface,

$$V_{10\mathrm{min}}(z_{ref}) = 1.03V_{1\mathrm{hr}}(z_{ref})$$

For a reference time period T_0 ($> \tau$) smaller than 3600 s, the gust factor can be calculated by:

$$G(z, \tau, T_0) = [0.2193\ln(\log_{10}T_0) - 0.7242] \times G(z, \tau, T_0 = 3600\mathrm{s})$$

APPENDIX 3

Fatigue Analysis for Floating Support Structures

CONTENTS

APPENDIX 3

Fatigue Analysis for Floating Support Structures

SECTION 1

Fatigue Analysis of Floating Support Structures

1 Introduction *(1 July 2020)*

Floating Offshore Wind Turbines are subjected to complex loading conditions that involve environmental loads, particularly those from wind, wave and current, and actions of the control, safety and protection systems. The loading conditions for the fatigue analysis of the Floating Support Structure are specified in Section 5-2.

The fatigue analysis method suggested in this Appendix assumes that the structural response of the Floating Support Structure can be reasonably represented by three components in distinctive frequency ranges relative to the predominant wave frequencies:

- Low-frequency component that mainly comprises the responses to wave and wind induced low-frequency motions;
- Wave-frequency component caused by direct wave loads or wave induced motions in the range of frequencies associated with the majority of wave energy;
- High-frequency component due to second and higher-order wave loads and aerodynamic responses of the wind turbine RNA.

The following Subsections in this Appendix provide suggested methods for the fatigue analysis of the Floating Support Structures, with consideration of the frequency range separation and the nonlinearity of the loading conditions. Alternative fatigue analysis methods may also be used.

3 Fatigue Analysis of the Floating Substructure in the Low Frequency Range *(1 July 2020)*

The wind and wave induced low-frequency motions depend on natural frequencies of rigid-body motions of the floating substructure. They are also affected by the type of the stationkeeping system and the mass of the structure and should preferably be analyzed using time-domain global motion analysis. The frequency range of the low-frequency motions should have a distinctive separation from the lowest predominant wave-frequency, which should be used as the upper limit frequency of the low-pass filter. If the separation of frequency range is not obvious, the upper limit frequency of the low-pass filter may be assumed to be 0.05 Hz. The time increment used in global motion analysis should be properly selected such that the peak of motion response can be captured.

For the Column-Stabilized and Spar-type floating substructure, natural frequencies of pitch and roll motions are usually smaller than predominant wave frequencies. The low-frequency pitch and roll motions could introduce significant structural loads in the following hull structural components:

- Bracing members and connections in a Truss Spar-type floating substructure
- Bracing members connecting the columns and pontoons in a Column-Stabilized floating substructure

The low-frequency pitch and roll motions could also cause significant structural loads in the Tower.

The pitch and roll motions derived from time-domain global motion analysis can be represented by Power Spectral Density (PSD) functions, which is further applied to the stress transfer functions for Column-stabilized or Spar-type floating substructure to obtain the stress PSD in the low frequency range.

To derive the stress transfer functions, linear static global finite element analyses may be performed using the floating substructure with a quasi-static unit pitch or roll motion. The inclined position may be achieved by imposing an assumed wind on the tower and current on the hull structure. Therefore, in addition to the gravity and buoyancy loads at the initial un-displaced position, the low-frequency loads include the assumed current and wind load, gravity load due to inclinations, varying buoyancy, and mooring/cable tension on the floating substructure at the rotated position. Stresses calculated at selected fatigue critical locations are the stress transfer functions. Appropriate stress concentration factors (SCFs) in accordance with 2/5.9.2 of the ABS *Guide for the Fatigue Assessment of Offshore Structures*should be incorporated into the stress transfer functions.

5 Fatigue Analysis of the Floating Substructure in the Wave Frequency Range *(1 July 2020)*

Wave-frequency responses of the floating substructure subjected to wave forces are normally the main cause of fatigue damage in the hull structures.

Wave forces on large floating bodies can be obtained using the diffraction/radiation analysis. Additional drag and inertia loads on slender bracing members may be computed by Morison Equations and should be appropriately considered in the motion analysis. Six degree-of-freedom rigid-body motion Response Amplitude Operators (RAOs) can be obtained from either frequency-domain or time-domain global motion analysis. RAOs of sectional loads and moments that are critical for structural designs can also be derived.

The spectral-based fatigue analysis method (see the ABS *Guide for the Fatigue Assessment of Offshore Structures*) can be used for fatigue analysis of the hull structure subjected to wave forces in the wave frequency range. The stress transfer functions should be determined through finite element analyses for the floating substructure subjected to wave forces and motions associated with a unit wave amplitude and various wave periods and directions.

7 Fatigue Analysis of the Floating Substructure in the High Frequency Range *(1 July 2020)*

A time-domain global motion analysis should be performed to identify the frequency range of high-frequency responses that should in general have a distinctive separation from the highest predominant wave-frequency to be used as the lower limit frequency of the high-pass filter. If the separation of frequency range is not obvious, the lower limit frequency of the high-pass filter may be assumed to be 0.25 Hz.

High-frequency loading may come from various sources such as the high-frequency wave loads, high-frequency aerodynamic loads transmitted from the tower, and vortex-induced-vibration (VIV) loads transmitted from the mooring lines or tendons. Those high-frequency loads may cause hull structural vibrations, in particular in the TLP-type floating substructure, where the load frequency is close to the structural natural frequency. Such vibrations and structural dynamic effects should be assessed and their effects on fatigue damage accumulation should be appropriately taken into account.

The rigid-body motions of the floating substructure due to high-frequency loads may be neglected for the Column-Stabilized or the Spar-type floating substructure. For the TLP-type floating substructure, high-frequency rigid-body motions of the floating substructure may be significant and, if necessary, the inertia forces in structural components induced by high-frequency rigid-body motions should be considered.

The stress PSDs in the high frequency range can be determined through the acceleration PSDs derived from time-domain global motion analysis and the transfer functions of stress components. To derive the stress transfer functions, linear static finite element analyses can be carried out for the floating substructure under a quasi-static inertial force associated with a unit acceleration and balancing loads at the tower-hull connection. Other loads from wind, wave, current, gravity load, buoyancy, and mooring/cable tension may be neglected.

For the TLP-type floating substructure, balancing loads may also be applied at the tendon porches. Appropriate stress SCFs in accordance with the 2/5.9.2 of the ABS *Guide for the Fatigue Assessment of Offshore Structures* should be incorporated into the stress transfer functions.

9 Calculation of Fatigue Damage of the Floating Substructure Subjected to Broadband Spectral Loading *(1 July 2020)*

The Floating Offshore Wind Turbinetypically has broadband responses that do not follow the Rayleigh distribution. Fatigue damage of the floating substructure can be calculated in various ways after the stress response spectra in the three distinctive frequency ranges are obtained through load/motion spectra and stress transfer functions. It is recommended that Dirlik's Method be used in the calculation of fatigue damage of the floating substructure. Either the summation of the stress spectra associated with the three frequency range or the summation of spectral moments of stress spectra associated with three frequency range may be used in the implementation of Dirlik's Method.

11 Time-Domain Fatigue Analysis for the Heave Plate and the Tower *(1 July 2020)*

Due to nonlinear aerodynamic loads and coupling effects of wind and wave loads, the time-domain fatigue analysis is preferred for the wind turbine Tower. By using this method, the motions and loads at the Tower top and base are first calculated through the time-domain global motion analysis of the Floating Offshore Wind Turbine. The structural dynamic analysis of the Tower can then be performed in the time domain with the motions and loads applied at the Tower top and base as boundary conditions.

Heave plates may be used in the Column-Stabilized or Spar-type floating substructure to improve the motion performance of the hull. The main load on the heave plate is hydrodynamic pressures induced by waves and motions of the hull.

Substantial nonlinear hydrodynamic loads are exerted on the heave plate due to the nonlinear viscous drag and relative hull motions. Where the heave plate is connected to other hull structures through bracing members, the global deformation of those bracing members due to bending and shear may also have a significant impact on the heave plate design.

To determine hydrodynamic loads on the heave plates, a global motion analysis should be performed in the time domain. The pressure distribution on the heave plate is typically not uniform, and the center of pressure could be away from the center of the plate. The pressure distribution is affected by the heave plate size and configuration, hull structure global pitch and roll motions, and combined wave and current loads. In order to calculate the pressure distributions that are required for the structural design, the heave plate is normally divided into a collection of smaller sub-panels. In the time domain analysis, these subpanels can be modeled using Morison elements with equivalent drag and inertia coefficients. Once the hydrodynamic forces on these equivalent Morison elements are obtained, they can be mapped to the finite element model of the heave plate for structural analyses, along with appropriate boundary conditions mapped from the global deformation of the structures connecting the heave plate to the main hull.