



GUIDE FOR BUILDING AND CLASSING

FLOATING OFFSHORE WIND TURBINE INSTALLATIONS

OCTOBER 2015 (Updated March 2018 – see next page)

**American Bureau of Shipping
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Updates

March 2018 consolidation includes:

- October 2015 version plus Corrigenda/Editorials

Foreword

This Guide provides criteria for the design, construction, installation and survey of permanently sited Floating Offshore Wind Turbine Installations. It addresses three principal areas: the Floating Support Structure, 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 support structures and foundations are provided in the *ABS Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations (BOWTI 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 Guide for Building and Classing Mobile Offshore Units* and the *ABS Rules for Building and Classing Floating Production Installations*.

This revision incorporates the following changes:

- 1-1/5 – A new optional class notion for the Rotor-Nacelle Assembly (RNA) is offered.
- 4-2/3.3 – Requirements are aligned with the new Appendix 2 for hurricane wind added to the *BOWTI Guide*.
- 4-6/17 – Guidance is provided on how the site assessment should be done with regard to electric network conditions.
- 5-2/3.1 – The requirement of considering the effect of malfunction of control systems on the integrity of the structural and stationkeeping system is clarified.
- 5-2/Table 1 – Additional requirements are provided for considering the directionality of wind and wave that may cause misaligned wave and wind conditions. A new design load case (new DLC 8.2) is added to account for possible fatigue damage during the temporary phase.
- 5-2/Table 2 – Further clarification is made of the condition of Floating Offshore Wind Turbine Installations in the robustness check.
- 6-1/1.1 and 6-2/1.1 – Reference is made to the new *ABS Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbine Installations*.
- 7-2/Table 2 – The fatigue design factor (FDF) is modified to address the unintended application of FDF = 1 to the non-critical, inspectable and repairable hull structures at or below the splash zone.
- 8-1/11 – A new Subsection is added to provide guidance on designing the non-redundant stationkeeping systems
- 8-3/Table 1 – The safety factor for ‘Damaged condition with one broken line’ is modified to better reflect actual practice.
- 8-3/7 – The case when the mooring line or tendon is over-designed (i.e., has higher than required breaking strength) for causes other than strength requirements is clarified. The design load used for the design of mooring hardware may be based on a value smaller than the breaking strength of the mooring lines or tendons. In such case, the maximum mooring/tendon tension multiplied by the safety factors defined in the Guide can be used.
- 8-3/9 – A new Subsection is added to provide guidance on how to account for the corrosion/wear in the design of mooring components.
- 8-5/9 and 8-5/11 – Two new Subsections are added to provide general guidance and design criteria for Suction Embedded Plate Anchor and Dynamically Installed Pile Anchor.

- 9-2/5.3 – The case when pre-approved procedures (repair, tow, etc.) are in place in lieu of installing pumps/blowers in the compartment is clarified.
- 10-1/11 – The requirements for safety outfitting for unmanned Floating Offshore Wind Turbine Installations are revised.
- Appendix 1 – A new Appendix is added that provides guidance on fatigue analysis of support structures.
- 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 TURBINE INSTALLATIONS

CONTENTS

CHAPTER 1	Conditions of Classification	1
	Section 1 Scope and Conditions of Classification	2
CHAPTER 2	Materials and Welding	17
	Section 1 General	18
CHAPTER 3	General Design Requirements	19
	Section 1 Design Considerations	20
CHAPTER 4	Environmental Conditions	24
	Section 1 Overview	26
	Section 2 Wind	27
	Section 3 Waves	34
	Section 4 Currents	36
	Section 5 Tides, Storm Surges, and Water Levels	38
	Section 6 Other Conditions	40
CHAPTER 5	Loads	43
	Section 1 Overview	44
	Section 2 Design Load Conditions	46
	Section 3 Determination of Environmental Loads	55
CHAPTER 6	Global Performance Analysis	60
	Section 1 General Requirements	61
	Section 2 Analysis Methodologies	64
CHAPTER 7	Design of Floating Support Structures	66
	Section 1 General Requirements	68
	Section 2 Steel Structures	70
	Section 3 Concrete Structures	78

CHAPTER 8	Design of Stationkeeping Systems	79
Section 1	General	81
Section 2	Design Conditions	83
Section 3	Steel Mooring and Tendon Systems	85
Section 4	Synthetic Fiber Ropes	89
Section 5	Anchor Holding Power	90
Section 6	Field Test	94
CHAPTER 9	Stability and Watertight/Weathertight Integrity	95
Section 1	General	96
Section 2	Stability	97
Section 3	Watertight/Weathertight Integrity	105
CHAPTER 10	Machinery, Equipment and Systems	106
Section 1	Design Requirements	107
CHAPTER 11	Surveys	109
Section 1	Surveys During Construction, Installation and Commissioning	111
Section 2	Surveys After Installation and Commissioning	118
Section 3	Risk-based Surveys for Maintenance of Class	123
APPENDIX 1	Fatigue Analysis for Floating Support Structures	124



CHAPTER 1 Conditions of Classification

CONTENTS

SECTION 1	Scope and Conditions of Classification.....	2
1	Classification	2
3	Classification Boundaries.....	2
5	Classification Symbols and Notations.....	2
5.1	Installations Built under ABS Survey	2
5.3	Installations Not Built under ABS Survey	3
5.5	Additional Class Notation	3
7	Rules for Classification	3
7.1	Application.....	3
7.3	References	3
7.5	Alternatives.....	3
9	Design Documentation to be Submitted	4
9.1	Reports.....	4
9.3	Design Data and Calculations	5
9.5	Design Plans of Floating Support Structure.....	6
9.7	Design Documentation of Stationkeeping System.....	7
9.9	Design Plans of Machinery and Systems	8
9.11	Additional Plans.....	9
11	Manuals and Procedures	9
11.1	Operating Manual.....	9
11.3	Procedures	10
13	Information Memorandum.....	10
15	Terms and Definitions	11
15.1	Types of Floating Support Structures	11
15.3	Terminology.....	12
17	Abbreviations and References.....	15
17.1	Abbreviations of Organizations.....	15
17.3	References	15



CHAPTER 1 Conditions of Classification

SECTION 1 Scope and Conditions of Classification

1 Classification

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 Installation are contained in the following Subsections.

3 Classification Boundaries (1 October 2015)

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

- i) The Floating Support Structure, which carries the wind turbine Rotor-Nacelle Assembly (RNA);
- 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 Rotor-Nacelle Assembly (RNA) may be included in the classification subject to the ABS Type Approval requirements of the *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

When the RNA is not included in the classification, the RNA installed on the ABS classed Floating Offshore Wind Turbine Installation is required to have a type certificate in accordance with IEC 61400-22 or other recognized standards. The RNA type certificate will be reviewed by ABS solely to verify that the information of the installed RNA is consistent with the design information, criteria and limitations considered in the classification of the Floating Offshore Wind Turbine Installation. ABS will not review or be responsible for the accuracy of the RNA type certificate. Use of the RNA which does not have an appropriate type certification or the wind turbine having a non-horizontal-axis configuration will be subject to special consideration by ABS.

5 Classification Symbols and Notations

The following class notations apply to the Floating Offshore Wind Turbine Installation, as defined in 1-1/3 and further in 1-1/15.3.8.

5.1 Installations Built under ABS Survey

Installations 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 Installation (Floating)

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

5.3 Installations Not Built under ABS Survey

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

A1 Offshore Wind Turbine Installation (Floating)

5.5 Additional Class Notation (1 October 2015)

The RNA, as defined in 1-1/15.3.25, may be considered for the classification at the Owner's request. Where the RNA are in full compliance with the requirements of the ABS Type Approval requirements of the *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*, the installation may be classed and distinguished in the *Record* by the optional class notation **RNA**.

7 Rules for Classification

7.1 Application

The requirements of this Guide are applicable to Floating Offshore Wind Turbine Installations as defined in 1-1/3 and further in 1-1/15.3.8.

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.

7.3 References

References are made in this Guide to ABS Rules and other criteria issued by ABS and other organizations. 1-1/17 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.

7.5 Alternatives (1 October 2015)

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 ABS's approval. The *ABS Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries* contains 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 Installation as a whole or to individual systems, subsystems or components. As appropriate, account must be given to remote hazards outside of the bounds of the system under consideration. 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 Installation as well as surveys during construction and surveys for maintenance of class.

Portions of the Floating Offshore Wind Turbine Installation 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

9 Design Documentation to be Submitted

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 Installation. The intended design life is also to be stated.

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 Installation within an offshore wind farm, and
- ii) The level of experience with conditions in the area where the Floating Offshore Wind Turbine Installation is to be located.

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

9.1 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.

9.1.1 Offshore Wind Farm Conditions

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 of 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 Installation.

9.1.2 Environmental Considerations

Reports on environmental considerations, as described in Chapter 4, Section 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 Installation, 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 Installation where these are not provided in other documentation.

9.1.3 Soil Data

Reports on soil data are to present the results of investigations or, when 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 Turbine Installations (BOWTI 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 listing of the predicted interaction between the soil and the anchoring structure of the stationkeeping system to be used in the design. 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.

9.1.4 Materials and Welding

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, when 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.

9.1.5 Model Test

If model testing is performed (for example as per 6-1/9 for the assessment of global performance, Chapter 5, Section 3 for the determination of environmental loads, or Chapter 9, Section 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.

9.3 Design Data and Calculations

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 which may be required in association with environmental considerations and soil data are described in 1-1/9.1.

9.3.1 Loadings

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

9.3.2 Stability

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

9.3.3 Dynamic Properties

Calculations of natural periods of the Floating Offshore Wind Turbine Installation 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 Installation is to be submitted.

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

9.3.4 Global Performance (1 October 2015)

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 for the mooring lines and anchors (or tendons and foundation) and other stationkeeping system components is to be submitted in accordance with Chapter 8.

9.3.5 Structural Responses

Calculations necessary to verify structural adequacy of the Floating Support Structure are to be submitted for review. The needed 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 Installation

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.

9.3.6 Other Calculations

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.

9.5 Design Plans of Floating Support Structure

Plans showing the scantlings, arrangements and details of the principal parts of the tower and hull structure of the Floating Offshore Wind Turbine Installation 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, export electrical 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
- Type, location and quantities of permanent ballast, if any
- Loadings for all decks
- Turbine tower scantlings
- Tower-hull connection 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
- Welding details and procedures
- Methods and locations for nondestructive testing
- Information in support of novel features utilized in the design, where applicable

9.7 Design Documentation of Stationkeeping System

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, turntable and disconnecting device
- Details of yoke (hard or soft) connecting the Floating Support Structure and the CALM/SALM structure
- Reports on wind farm conditions, environmental considerations and soil data, as required in 1-1/9.1
- Global performance analysis report, as required in 1-1/9.3.4
- Model test report when the design loads are based on model tests in a wave basin (see 1-1/9.1.5)
- Thruster specifications and calculations of a system with dynamic positioning system for thruster forces and power to counteract environmental forces.

9.9 Design Plans of Machinery and Systems

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

9.9.1 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

9.9.2 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

9.9.3 Fire Protection and Personnel Safety Design Plans

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 Wind Turbine Installation.

- 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)

9.9.4 Design Plans for Other Machinery and Systems

Submission of design plans for other machinery and systems which are described in Chapter 10 but not specified in 1-1/9.9.1 through 1-1/9.9.3 of this Guide is to follow 1-1-4/3 of the *MODU Rules*, where applicable.

9.11 Additional Plans

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 required.

11 Manuals and Procedures

11.1 Operating Manual

The Operating Manual pertaining to the safe operation of the Floating Offshore Wind Turbine Installation is to be prepared and submitted for review. A copy of the Operating Manual is preferably to be stored onboard of the Floating Offshore Wind Turbine Installation. Alternatively, the Operating Manual may be retained by the Owner and made readily available to the ABS Surveyor and to 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 Installation, including major dimensions, lightship characteristics
- ii) A general description and the maintenance record of the RNA
- iii) Summaries of approved modes of operation (See Chapter 5, Section 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)
 - *(1 October 2015) 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
- vi) Disconnecting and reconnecting procedure, if applicable, for operating disconnectable mooring systems

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

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

11.3 Procedures

Procedures are to be submitted for the following:

- Installation Procedures
- Hook-Up Procedures for connecting the stationkeeping system to the Floating Support Structure
- Startup and Commissioning Procedures
- Survey and Inspection Planning Document
- Underwater Inspection Procedure or, if applicable, Drydocking Survey Procedure
- Disconnecting and Reconnecting Procedure, if applicable, for operating disconnectable mooring systems

13 Information Memorandum

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 their 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 Installation, the following:

- Specifications of turbine RNAs to be installed
- 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 Installation
- Description of the safety, protective, security and trespass avoidance systems provided
- Description of the modes of operation
- 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 both the Floating Offshore Wind Turbine Installation and the RNA
- Description of disconnecting, transportation and reconnecting procedures for maintenance and repair operations, if applicable

15 Terms and Definitions

15.1 Types of Floating Support Structures

15.1.1 TLP-Type Floating Support Structures (1 October 2015)

A TLP-type Floating Support Structure is a vertically moored, buoyant structural system wherein the excess buoyancy of the platform maintains tension in the stationkeeping system.

A TLP-type Floating Support Structure 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 Support Structure. The foundation system is used to anchor the tendons to the seafloor.

15.1.2 Spar-Type Floating Support Structures (1 October 2015)

A Spar-type Floating Support Structure 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 Support Structure 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.

15.1.3 Column-Stabilized Floating Support Structures

A column-stabilized Floating Support Structure consists of a topside structure connected to the underwater hull or footings by columns or caissons. The Floating Support Structure 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 Support Structure. The Tower may be connected directly to the column or caisson or to the topside structure.

15.1.4 Other Types of Floating Support Structures

Configurations of the Floating Support Structure that do not belong to the types described in 1-1/15.1.1 through 1-1/15.1.3.

15.3 Terminology

15.3.1 Material Applications Categories

The application of structural members in the Floating Support Structure is to be in accordance with the categories listed in this Paragraph.

15.3.1(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.

15.3.1(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.

15.3.1(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.

15.3.2 Consultant

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

15.3.3 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

15.3.4 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

15.3.5 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

15.3.6 Emergency Shutdown

Rapid shutdown of the wind turbine triggered by a protection function or by manual intervention

15.3.7 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.

15.3.8 Floating Offshore Wind Turbine Installation (1 October 2015)

A Floating Offshore Wind Turbine Installation encompasses three principal areas: the Floating Support Structure (see 1-1/15.3.9) for carrying the wind turbine RNA (see 1-1/15.3.25), the Stationkeeping System (see 1-1/15.3.28) and onboard machinery, equipment and systems **including applicable marine systems and associated equipment and machinery, safety systems and associated equipment, and lifesaving appliances machinery.**

In this Guide, the Floating Offshore Wind Turbine Installation does not include the RNA.

15.3.9 Floating Support Structure

A Floating Support Structure of an offshore wind turbine is a site dependent offshore structure supported by buoyancy and maintained on location by the Stationkeeping System. The Floating Support Structure consists of the Tower (see 1-1/15.3.32) and the Hull (see 1-1/15.3.12) structure.

15.3.10 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

15.3.11 Gust

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

15.3.12 Hull

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

15.3.13 Hub Height (1 October 2015)

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

15.3.14 Idling

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

15.3.15 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

15.3.16 Mean Wind Speed

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

15.3.17 Normal Shutdown

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

15.3.18 Offshore Wind Farm

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

15.3.19 Omni-directional (Wind, Waves or Currents)

Acting in all directions

15.3.20 Owner

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

15.3.21 Parked

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

15.3.22 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.

15.3.23 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

15.3.24 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.

15.3.25 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.

15.3.26 Splash Zone

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

15.3.27 Standstill

Condition of a wind turbine that is not rotating

15.3.28 Stationkeeping System

System capable of limiting the excursions of the Floating Support Structure within prescribed limits, maintaining the intended orientation, and helping to limit motions at Tower top

15.3.29 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.

15.3.30 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.

15.3.31 Tendon

A system of components, which form a link between the Hull structure and the Foundation System for the purpose of restraining motion of the TLP-type Floating Support Structure in response to environmental and other loading within specified limits

15.3.32 Tower

Structure component which connects the Hull structure to the Rotor-Nacelle Assembly

15.3.33 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

15.3.34 Uni-directional (Wind, Waves or Currents)

Acting in a single directions

15.3.35 Water Depth

Vertical distance between the sea floor and the Still Water Level

15.3.36 Wind Profile (Wind Shear Law)

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

15.3.37 Yaw Misalignment

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

17 Abbreviations and References

17.1 Abbreviations of Organizations

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

17.3 References (1 October 2015)

- i) ABS *FPI Rules – ABS Rules for Building and Classing Floating Production Installations*
- ii) ABS *MODU Rules – ABS Rules for Building and Classing Mobile Offshore Drilling 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 *Steel Vessel Rules – ABS Rules for Building and Classing Steel Vessels*
- vi) ABS *Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations*
- vii) ABS *Guide for Building and Classing Gravity-Based Offshore LNG Terminals*
- viii) ABS *Guide for Buckling and Ultimate Strength Assessment for Offshore Structures*
- ix) ABS *Guide for the Fatigue Assessment of Offshore Structures*
- x) ABS *Guide for Nondestructive Inspection of Hull Welds*
- xi) ABS *Guide for Surveys Using Risk Based Inspection for the Offshore Industry*
- xii) ABS *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques*
- xiii) ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*
- xiv) ABS *Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbine Installations*
- xv) ABS *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*
- xvi) ABS *Guidance Notes on Review and Approval of Novel Concepts*
- xvii) AISC *Manual of Steel Construction*
- xviii) API Bulletin 2INT-MET, *Interim Guidance on Hurricane Conditions in the Gulf of Mexico*
- xix) API Bulletin 2N, *Interim Planning, Designing and Constructing Fixed Offshore Structures in Ice Environments*
- xx) API RP 2A-LRFD, *Recommended Practice for Planning Designing and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design*
- xxi) API RP 2A-WSD, *Recommended Practice for Planning Designing and Constructing Fixed Offshore Platforms – Working Stress Design*
- xxii) API RP 2SK, *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*

- xxiii) API RP 2T, *Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*
- xxix) API SPEC 17E, *Specification for Subsea Umbilicals*
- xxv) IEC 61400-1, *Wind Turbines – Part 1: Design Requirements*, 3rd Edition, 2005
- xxvi) IEC 61400-3, *Wind Turbines – Part 3: Design Requirements for Offshore Wind Turbines*”, 1st Edition, 2009
- xxvii) IEC 61400-24, *Wind Turbines – Part 24: Lightning protection*, 1st Edition, 2010.
- xxviii) IEEE 1120, *IEEE Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems*
- xxix) ISO 2533, *Standard Atmosphere*
- xxx) ISO 19904-1, *Petroleum and natural gas industries – Floating Offshore Structures, Part 1: Monohulls, Semi-submersibles and Spars*
- xxxi) ISO 19906, *Petroleum and natural gas industries - Arctic offshore structures*
- xxxii) NACE SP0108, *Standard Practice: Corrosion Control of Offshore Structures by Protective Coatings*
- xxxiii) NACE SP0176, *Standard Practice: Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production*



CHAPTER 2 Materials and Welding

CONTENTS

SECTION 1	General.....	18
1	Metallic Materials	18
3	Welding	18
5	Concrete.....	18
7	Mooring Chains and Accessories	18
9	Fiber Ropes	18



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 *MODU Rules*. Guidance on determining the material application category (see 1-1/15.3.1) 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 *MODU Rules* is to be used to establish weld designs for the steel Floating Support Structure.

5 Concrete

Properties of the concrete are to comply with 2-1/3 of the *ABS Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations*, 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

SECTION 1	Design Considerations	20
1	General	20
3	Safety Level	20
5	Design Life	20
7	Environmental Conditions	21
9	Design Load Conditions and Load Calculations	21
11	Global Performance Analyses	22
13	Structural Design	22
15	Stationkeeping System	22
17	Stability and Watertight/Weathertight Integrity	23
19	Structural Material Selection, Welding and Connection	23
21	Corrosion Protection and Control	23
23	Operating Manual	23



CHAPTER 3 General Design Requirements

SECTION 1 Design Considerations

1 General *(1 October 2015)*

The Floating Support Structure, 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 Installation can fulfill its intended functions during its design life and meet specified minimum requirements for serviceability and operability.

3 Safety Level *(1 October 2015)*

The design criteria specified in this Guide are intended for the unmanned Floating Offshore Wind Turbine Installation 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 Installation. Consequences of failure deal with loss of life, environmental pollution, financial loss and potential negative impact to the industry.

Since the Floating Support Structure 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 considering that:

- 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 Turbine Installations located in a close proximity, failure of an individual stationkeeping system could potentially cause extensive damage to many other floating offshore wind turbines and electrical 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

The design life of the Floating Offshore Wind Turbine Installation 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 Installation 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.

7 Environmental Conditions

The Floating Offshore Wind Turbine Installation 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 Installation 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 when 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 Installation. 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 Installation can endure such responses without causing catastrophic consequences.

9 Design Load Conditions and Load Calculations

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 Installation 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 Installation 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.

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

- 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 when subjected to aggregate environmental and turbine operational loadings

Following these considerations and in particular because dynamic responses of bottom-founded offshore wind turbines exhibit a wide scattering of sensitivity to the variation of environmental conditions, the *ABS Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations* requires the application of the 100-year return storm condition to the design of support structures of bottom-founded offshore wind turbines to be installed at a site where extreme environmental conditions are governed by tropical cyclones.

In contrast to bottom-founded offshore wind turbines, the Floating Offshore Wind Turbine Installation having the typical hull types as defined in 1-1/15.1.1 through 1-1/15.1.3 show a very 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

Global performance analyses of the Floating Offshore Wind Turbine Installation are used to determine the global effects of environmental loads and other loads on the turbine RNA, the Floating Support Structure, the stationkeeping system, and the export electrical cable system. 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, the Floating Support Structure, the stationkeeping system, and the export electrical 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 Floating Support Structure, the stationkeeping system, and the export electrical cable system.

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

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

The Floating Support Structure 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 dynamic positioning system, a thruster-assisted mooring consisting of actively controlled thrusters, or a mooring system with the ability of changing mooring line tensions.

17 Stability and Watertight/Weathertight Integrity

Adequacy of stability of the Floating Support Structure 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

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*.

21 Corrosion Protection and Control

A corrosion protection and control system utilizing 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 Installation, 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.

23 Operating Manual

The Operating Manual, as required in 1-1/11.1, 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 Installation.

CHAPTER 4 Environmental Conditions

CONTENTS

SECTION 1	Overview	26
1	General	26
3	Environmental Factors to be Considered	26
SECTION 2	Wind.....	27
1	General	27
3	Wind Properties	27
3.1	Wind Speed and Turbulence	27
3.3	Wind Profile	28
3.5	Wind Spectrum and Spatial Coherence.....	29
5	Long-Term and Extreme Value Predictions.....	29
7	Wind Conditions.....	29
9	Normal Wind Conditions	30
9.1	Normal Wind Profile Model (NWP)	30
9.3	Normal Turbulence Model (NTM)	30
11	Extreme Wind Conditions	30
11.1	Extreme Wind Speed Model (EWM)	30
11.3	Extreme Operating Gust (EOG).....	31
11.5	Extreme Turbulence Model (ETM).....	31
11.7	Extreme Direction Change (EDC).....	31
11.9	Extreme Coherent Gust with Direction Change (ECD)	32
11.11	Extreme Wind Shear (EWS)	33
13	Survival Wind Conditions.....	33
13.1	Survival Wind Speed Model (SurWM)	33
FIGURE 1	Vector Components of Turbulent Wind Velocity	28
SECTION 3	Waves	34
1	General	34
3	Normal Sea State (NSS).....	34
5	Severe Sea State (SSS)	35
7	Extreme Sea State (ESS)	35
9	Survival Sea State (SurSS).....	35
11	Breaking Waves.....	35

SECTION 4	Currents	36
1	Currents	36
3	Normal Current Model (NCM)	36
5	Extreme Current Model (ECM)	36
7	Survival Current Model (SurCM)	37
SECTION 5	Tides, Storm Surges, and Water Levels	38
1	General	38
3	Normal Water Level Range (NWLR)	38
5	Extreme Water Level Range (EWLR)	38
7	Survival Water Level Range (SurWLR)	39
	FIGURE 1 Definition of Water Levels	39
SECTION 6	Other Conditions	40
1	Temperature	40
3	Air Density	40
5	Ice and Snow Accumulation	40
7	Marine Growth	40
9	Seismicity and Earthquake Related Phenomena	40
	9.1 Levels of Earthquake Conditions	40
	9.3 Regional and Site-specific Data	41
	9.5 Other Earthquake Related Phenomena	41
11	Sea Ice or Lake Ice	41
13	Soil Conditions	41
15	Lightning	41
17	Electric Network Conditions	42



CHAPTER 4 Environmental Conditions

SECTION 1 Overview

1 General

Environmental conditions to which the Floating Offshore Wind Turbine Installation 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 Installation is to be transported and installed.

Environmental phenomena that influence the pre-service and in-service phases of the Floating Offshore Wind Turbine Installation 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 1-1/9.1. 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

In general, the design of the Floating Offshore Wind Turbine Installation 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 Installation.

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 Chapter 5, Section 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.

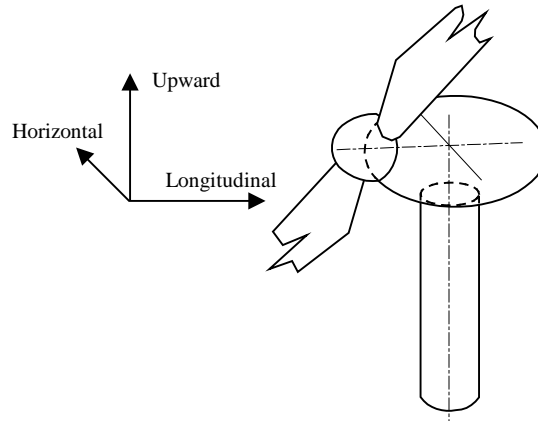
Conversion of a mean wind speed from one averaging duration to another is to be based on site-specific wind conditions. Use of conversion factors in recognized industry standards appropriate to the installation site may be acceptable and is subject to approval by ABS.

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 $t = 3600/V_f$, where V_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/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



3.3 Wind Profile (1 October 2015)

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 storm wind conditions, the mean wind speed profile may be represented by the following logarithmic wind shear law as recommended by API Bulletin 2INT-MET (2007). It is expressed using the 1-hour mean wind speed at 10 m (32.8 ft) above the SWL.

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

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

$$\begin{aligned}
 C &= 0.0573 \sqrt{1 + 0.15V_0 / \phi}, \text{ (dimensionless)} \\
 V_0 &= \text{1-hour mean wind speed at 10 m (32.8 ft) above the SWL, in m/s (ft/s)} \\
 I_u(z) &= \text{turbulence intensity, [i.e., the ratio of the wind speed standard deviation to the mean wind speed, at height } z \text{ (dimensionless)]} \\
 &= 0.06[1 + 0.043V_0/\phi] \left(\frac{z}{10\phi} \right)^{-0.22} \\
 \phi &= \text{unit conversion factor (dimensionless)} \\
 &= 1 \quad \text{when using SI units (m, m/s)} \\
 &= 3.28 \quad \text{when using US Customary units (ft, ft/s)}
 \end{aligned}$$

Guidance on the wind profile suitable for tropical cyclones (also known as hurricanes or typhoons) is provided in Appendix 2 of the *BOWTI Guide*.

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 October 2015)

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 B of IEC 61400-1 (2005), may be applied.

For the tropical cyclone wind, API Bulletin 2INT-MET (2007) recommends using the NPD (Frøya) wind spectrum in conjunction with the two-point coherence function. Refer to Appendix 1 of the *ABS BOWTI Guide* for the definition.

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

A wind condition for the design of the Floating Offshore Wind Turbine Installation is represented by a steady mean flow and associated turbulence. 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 Installation.

The design wind conditions for the Floating Offshore Wind Turbine Installation are specified in 4-2/9 through 4-2/13. The load case descriptions in Chapter 5, Section 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)

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 12.3 of IEC 61400-3 (2009) 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 October 2015)

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 Chapter 5, Section 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)
	=	$V_{10min,1-yr}$ for 1-year return extreme wind condition
	=	$V_{10min,50-yr}$ for 50-year return extreme wind condition
$V_{10min,1-yr}$	=	10-minute mean wind speed at hub height with a return period of 1 year, in m/s (ft/s)
$V_{10min,50-yr}$	=	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:

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

Alternatively, 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.

Guidance on the wind profile, the turbulence intensity and the gust factor suitable for tropical cyclones (also known as hurricanes or typhoons) is provided in Appendix 2 of the *BOWTI Guide*.

11.3 Extreme Operating Gust (EOG)

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

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

where

- $V_{3sec,1-yr}$ = 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/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 $z \leq 60$ m (196.8 ft)
 - = 42 m (137.8 ft) when $z \geq 60$ m (196.8 ft)
- D = rotor diameter, in m (ft)

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

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

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

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/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)

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

$$\theta_e = \pm 4 \arctan \left(\frac{\sigma_{NTM}}{V_{hub} (1 + 0.1D / \Lambda_1)} \right) \quad -180^\circ \leq \theta_e \leq 180^\circ$$

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/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:

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

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.

11.9 Extreme Coherent Gust with Direction Change (ECD)

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

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

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

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

where

$$\begin{aligned} V(z) &= \text{normal wind profile defined in 4-2/9.1, in m/s (ft/s)} \\ T &= \text{rise time of gust wind, in second} \\ &= 10 \text{ s} \\ z &= \text{height above the SWL, in m (ft)} \end{aligned}$$

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

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

where

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

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:

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

The time history of transient horizontal shear is given by:

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

where

V_{hub}	=	10-minute mean wind speed at hub height, as defined in 5-2/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

The development of wave data is to reflect conditions at the installation site and the type of Floating Offshore Wind Turbine Installation. 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 particular 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.

The design wave conditions for the design of the Floating Offshore Wind Turbine Installation are described below in 4-3/3 through 4-3/9. The design load conditions defined in Chapter 5, Section 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/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., $H_{s,NSS} = E[H_s | V_{hub}]$). 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)

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 Wind Turbine Installation.

7 Extreme Sea State (ESS)

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 $H_{s,1-yr}$ or $H_{s,50-yr}$ for the extreme significant wave height with a return period of 1 year or 50 years, respectively. The values of $H_{s,1-yr}$ and $H_{s,50-yr}$ 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 $H_{s,1-yr}$ and $H_{s,50-yr}$ 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 Wind Turbine Installation.

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

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 (2009), Annex C.



CHAPTER 4 Environmental Conditions

SECTION 4 Currents

1 Currents

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 Sections 2.3.3 and 2.3.4 of API RP 2A-WSD (2007).

The current models for the design of the Floating Offshore Wind Turbine Installation are described below in 4-4/3 through 4-4/7. The design load conditions defined in Chapter 5, Section 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 5-2/3.1xiii).

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 Chapter 5, Section 2.



CHAPTER 4 Environmental Conditions

SECTION 5 Tides, Storm Surges, and Water Levels

1 General

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/Figure 1.

For the TLP-type Floating Support Structure (see 1-1/15.1.1), 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 Installation are defined in 4-5/3 through 4-5/7. The design load conditions defined in Chapter 5, Section 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)

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 Chapter 5, Section 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) in order to determine the most unfavorable responses of the Floating Offshore Wind Turbine Installation.

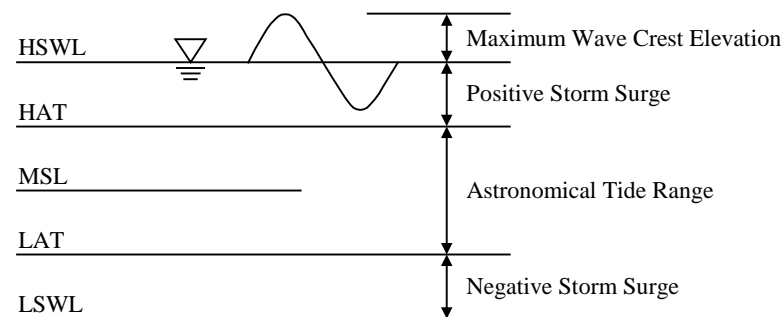
In the absence of the long term joint probability distribution of metocean parameters including water level, the following water levels are to be considered as a minimum:

- The Mean Sea Level (MSL), as defined in 1-1/15.3.15
- 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) in 4-5/5, but with a return period longer than 50 years, as specified in Chapter 5, Section 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

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 Installation.

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

Marine growth is to be considered in the design of the Floating Offshore Wind Turbine Installation. 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

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

9.1 Levels of Earthquake Conditions

The magnitudes of the parameters characterizing the earthquakes with return periods appropriate to the design life of the Floating Offshore Wind Turbine Installation 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 Installation.
- 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

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

The 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 Installation. Both vertical and horizontal accelerations are to be considered for the design of the TLP-type Floating Support Structure 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

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

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 Installation, provided that safety is not compromised.

17 Electric Network Conditions (*1 October 2015*)

The assessment of electric network conditions is to be performed in accordance with IEC 61400-3 (2009).

CHAPTER 5 Loads

CONTENTS

SECTION 1	Overview	44
1	General	44
3	Types of Loads to be Considered	44
3.1	Permanent Loads	44
3.3	Variable Loads	44
3.5	Environmental Loads	45
SECTION 2	Design Load Conditions	46
1	General	46
3	Definition of Design Load Cases (DLCs)	46
3.1	General	46
3.3	DLCs for Floating Support Structures	48
3.5	DLCs for Stationkeeping Systems	49
5	Definition of Survival Load Cases (SLCs)	54
TABLE 1	Design Load Cases	50
TABLE 2	Survival Load Cases	54
SECTION 3	Determination of Environmental Loads	55
1	General	55
3	Wind Loads	55
3.1	Aerodynamic Loads Generated by the Rotor	55
3.3	Rotor Thrust Force	55
3.5	Wind Forces on Exposed Structural Components	56
5	Wave Loads	57
7	Current Loads	58
9	Ice and Snow Accumulation Induced Loads	58
11	Earthquake Loads	58
13	Marine Growth	59
15	Ice Loads	59
TABLE 1	Shape Coefficients C_s	57



CHAPTER 5 Loads

SECTION 1 Overview

1 General

This Section pertains to the identification, definition and determination of the loads which the Floating Offshore Wind Turbine Installation 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 Installation, 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

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

3.1 Permanent Loads

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 Support Structure
- 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

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) Weight of personnel and consumable supplies
- ii) Forces exerted by lifting equipment during maintenance and repair
- iii) 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
- iv) Loads associated with helicopter operations, if applicable

- v) Loads associated with operations of an adjustable ballast system, if applicable
- vi) 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.
- vii) 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 Wind Turbine Installation 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

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 Installation are specified in Chapter 5, Section 2. Calculations of environmental loads are described in Chapter 5, Section 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

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

- i) Design Load Cases (DLCs), which are defined to verify the design adequacy of the Floating Offshore Wind Turbine Installation 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 Installation is subjected to the environmental conditions that are more severe than the extreme design environmental conditions.

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

3 Definition of Design Load Cases (DLCs)

3.1 General (1 October 2015)

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

As a minimum, the DLCs defined in 5-2/Table 1 are to be assessed in the design of the Floating Offshore Wind Turbine Installation. 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/Table 1 are adapted from “Table 1 – Design load cases” of IEC 61400-3 (2009) for bottom-founded offshore wind turbines, with various modifications to address unique load and response characteristics of the Floating Offshore Wind Turbine Installation.

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 Installation 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 Installation 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 installation are to be taken into account in the definition of the DLCs.

The descriptions and analysis requirements for DLCs defined in 5-2/Table 1, including the amendment to the original DLCs specified in IEC 61400-3 (2009), are presented as follows. Further reference is to be made to Section 7.4 and Section 7.5.4 of IEC 61400-3 (2009).

The following statements pertain to the required design load cases in 5-2/ Table 1.

- i) The DLC serial numbers are in general in accordance with those specified in IEC 61400-3 (2009).
- ii) The DLCs defined in 5-2/Table 1 are for the design of the Floating Support Structure and the stationkeeping system of the Floating Offshore Wind Turbine Installation. As such, DLC 1.1 required by IEC 61400-3 (2009) for the calculation of the ultimate loads acting on the RNA is not included in 5-2/Table 1.
- iii) The DLCs associated with regular (deterministic) wave conditions as defined in IEC 61400-3 (2009) are not applicable to the design of the Floating Offshore Wind Turbine Installation and therefore not included in 5-2/Table 1. The indicators, 'a', 'b' and 'c', attached to the DLC serial numbers are also removed for the same reason.
- 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 shutdown may need to be considered instead of the normal shutdown.
- v) The design environmental conditions referred in 5-2/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/Table 1. This differs from IEC 61400-3 (2009) 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 required 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. Any reduction to the return period of environmental conditions is subject to special consideration by ABS.
- 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 $+180^\circ$ 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 Wind Turbine Installation. 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 Installation.
- x) For those load cases, including DLC 6.1, 6.2, 6.3, 7.1 and 8.2, which in general require time domain dynamic simulations for the combined extreme turbulent wind and stochastic storm waves, the simulation time duration may differ from the reference periods of wind speed and significant wave height. Two scaling factors, k_1 and k_2 , are introduced in 5-2/Table 1 for the 10-minute mean wind speed and the significant wave height of a storm wave respectively to take this time-scale difference into account.

IEC 61400-3 (2009), Section 7.4.6 recommends to use one hour as the simulation time duration. As a result, $k_1 = 0.95$ for the 10-minute mean wind speed and $k_2 = 1.09$ for the extreme significant wave height, assuming that the reference period of extreme wave condition is 3 hours; the wave heights follow the Rayleigh distribution; and the number of waves in 3 hours is approximately 1000. The turbulence standard deviation applied in the 1-hour simulation duration is increased by 0.2 m/s (0.66 ft/s) relative to the value associated with the 10-minute mean wind speed.

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 Chapter 6, Section 2.

- xi) Where a wind speed range is indicated in 5-2/Table 1, wind speeds leading to the most unfavorable responses are to be considered for the design of the Floating Offshore Wind Turbine Installation. 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 1-1/15.3.23), 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 Installation. 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.
- 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 Bulletin 2INT-MET, 2007), as appropriate to site conditions and a specific design of the Floating Offshore Wind Turbine Installation. 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/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) (1 October 2015) 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) (1 October 2015) 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 be determined to produce the most unfavorable effect on the Support Structure.

3.3 DLCs for Floating Support Structures

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

For each DLC defined in 5-2/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 Installation. 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 Installation.

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/Table 1 are specified in Chapter 7, Section 2.

3.5 DLCs for Stationkeeping Systems

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

The DLCs specified in 5-2/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 effect 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 Support Structure 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 Support Structures located in seismically active areas (see 4-6/9)

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 October 2015)

<i>Turbine Condition</i>	<i>DLC</i>	<i>Wind Condition</i>	<i>Waves</i>	<i>Wind and Wave Directionality</i>	<i>Sea Currents</i>	<i>Water Level</i>	<i>Other Conditions</i>	<i>Type of Analysis</i>	<i>Safety Factor</i>
1) Power production	1.2	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or \geq MSL		F	FDF
	1.3	ETM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	MIS, MUL	NCM	MSL		S	N
	1.4	ECD $V_{hub} = V_r \pm 2 \text{ m/s (6.6 ft/s)}$	NSS $H_s = E[H_s / V_{hub}]$	MIS, wind direction change	NCM	MSL		S	N
	1.5	EWS $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	MIS, MUL	NCM	MSL		S	N
	1.6	NTM $V_{in} \leq V_{hub} \leq V_{out}$	SSS $H_s = H_{s,SSS}$	MIS, MUL	NCM	NWLR		S	N
2) Power production plus occurrence of fault	2.1	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	MSL	Control system fault or loss of electrical network	S	N
	2.2	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	MSL	Protection system or preceding internal electrical fault	S	A
	2.3	EOG $V_{hub} = V_r \pm 2 \text{ m/s (6.6 ft/s)}$ and V_{out}	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	MSL	External or internal electrical fault including loss of electrical network	S	A
	2.4	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	NWLR or \geq MSL	Control, protection, or electrical system faults including loss of electrical network	F	FDF

TABLE 1 (continued)
Design Load Cases (1 October 2015)

<i>Turbine Condition</i>	<i>DLC</i>	<i>Wind Condition</i>	<i>Waves</i>	<i>Wind and Wave Directionality</i>	<i>Sea Currents</i>	<i>Water Level</i>	<i>Other Conditions</i>	<i>Type of Analysis</i>	<i>Safety Factor</i>
3) Start-up	3.1	NTM $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	NWLR or \geq 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 $V_{in} \leq V_{hub} \leq V_{out}$	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	NWLR or \geq MSL		F	FDF
	4.2	EOG $V_{hub} = V_r \pm 2$ m/s (6.6 ft/s) and V_{out}	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	MSL		S	N
	4.3	NTM $V_{in} \leq V_{hub} \leq V_{out}$	SSS $H_s =$ maximum operating limit	COD, UNI	NCM	NWLR	sea state exceeding the maximum operational limit	S	N
5) Emergency shutdown	5.1	NTM $V_{hub} = V_r \pm 2$ m/s (6.6 ft/s) and V_{out}	NSS $H_s = E[H_s / V_{hub}]$	COD, UNI	NCM	MSL		S	N

TABLE 1 (continued)
Design Load Cases (1 October 2015)

<i>Turbine Condition</i>	<i>DLC</i>	<i>Wind Condition</i>	<i>Waves</i>	<i>Wind and Wave Directionality</i>	<i>Sea Currents</i>	<i>Water Level</i>	<i>Other Conditions</i>	<i>Type of Analysis</i>	<i>Safety Factor</i>
6) Parked (standing still or idling)	6.1	EWM $V_{hub} = k_1 V_{10min, 50-yr}$	ESS $H_s = k_2 H_{s, 50-yr}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level		S	N
	6.2	EWM $V_{hub} = k_1 V_{10min, 50-yr}$	ESS $H_s = k_2 H_{s, 50-yr}$	MIS, MUL	ECM 50-yr Currents	EWLR 50-yr Water Level	Loss of electrical network	S	A
	6.3	EWM $V_{hub} = k_1 V_{10min, 1-yr}$	ESS $H_s = k_2 H_{s, 1-yr}$	MIS, MUL	ECM 1-yr Current	NWLR	Extreme yaw misalignment	S	N
	6.4	NTM $V_{hub} \leq V_{10min, 1-yr}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or \geq MSL		F	FDF
7) Parked and fault conditions	7.1	EWM $V_{hub} = k_1 V_{10min, 1-yr}$	ESS $H_s = k_2 H_{s, 1-yr}$	MIS, MUL	ECM 1-yr Current	NWLR		S	A
	7.2	NTM $V_{hub} \leq V_{10min, 1-yr}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or \geq 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	To be defined by the Fabricator or Owner						F	FDF
	8.3	EWM $V_{hub} = k_1 V_{10min, 1-yr}$	ESS $H_s = k_2 H_{s, 1-yr}$	MIS, MUL	ECM 1-yr Current	NWLR		S	A
	8.4	NTM $V_{hub} \leq V_{10min, 1-yr}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NCM	NWLR or \geq MSL	No grid during installation period	F	FDF

TABLE 1 (continued)
Design Load Cases (1 October 2015)

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)	A	abnormal (5-2/3.3)
EDC	extreme direction change (4-2/11.7)	T	temporary (5-2/3.3)
EOG	extreme operating gust (4-2/11.3)	FDF	fatigue design factor (Chapter 7 and Chapter 8)
ESS	extreme sea state (4-3/7)	H_s	significant wave height
ETM	extreme turbulence model (4-2/11.5)	$H_{s,1\text{-yr}}$	significant wave heights with a return period of 1-year (4-3/7)
EWLR	extreme water level range (4-5/5)	$H_{s,50\text{-yr}}$	significant wave heights with a return period of 50-year (4-3/7)
EWM	extreme wind speed model (4-2/11.1)	$H_{s,SSS}$	significant wave height of the severe sea state (4-3/5)
EWS	extreme wind shear (4-2/11.11)	k_1	simulation time scaling factors for 10-minute mean wind speed (5-2/3.1)
MIS	misaligned wind and wave directions	k_2	simulation time scaling factors for significant wave height (5-2/3.1)
MSL	mean sea level (4-5/Figure 1)	T_p	peak period of wave spectrum
MUL	multi-directional wind and wave	$V_{10\text{min},1\text{-yr}}$	10 minute mean wind speed at hub height with a return period of 1 year (4-2/11)
NCM	normal current model (4-4/3)	$V_{10\text{min},50\text{-yr}}$	10 minute mean wind speed at hub height with a return period of 50 year (4-2/11)
NTM	normal turbulence model (4-2/9.3)	V_{hub}	10-minute mean wind speed at hub height (4-2/3.1)
NWLR	normal water level range (4-5/3)	V_{in}	cut-in wind speed (1-1/15.3.3)
NWP	normal wind profile model (4-2/9.1)	V_{out}	cut-out wind speed (1-1/15.3.4)
NSS	normal sea state (4-3/3)	V_r	rated wind speed (1-1/15.3.23)
SSS	severe sea state (4-3/5)	$V_r \pm 2 \text{ m/s (6.6 ft/s)}$	Sensitivity to the wind speeds in the range is to be analyzed (5-2/3.1)
UNI	uni-directional wind and wave directions		

5 Definition of Survival Load Cases (SLCs)

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/Table 2 are to be assessed in the robustness check of the Floating Offshore Wind Turbine Installation. 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 Bulletin 2INT-MET). 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 Support Structure, additional robustness checks of its stationkeeping system are to include

- i) The assessment of the minimum tendon tension for the Floating Offshore Wind Turbine Installation subjected to the SLCs defined in 5-2/Table 2;
- ii) The strength assessment of the ‘one-tendon removed’ case, if applicable, for the Floating Offshore Wind Turbine Installation 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 Installation 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 October 2015)

<i>Design Condition</i>	<i>Wind Condition</i>	<i>Waves</i>	<i>Wind and Wave Directionality</i>	<i>Sea Currents</i>	<i>Water Level</i>
Parked RNA; Intact Blades; Intact Hull and Stationkeeping System	SurWM $V_{hub} = k_1 V_{10min,n-yr}$	SurSS $H_s = k_2 H_{s,n-yr}$	MIS, MUL	SurCM n-yr Currents	SurWLR n-yr Water Level
Parked RNA; Damaged Blade(s); Intact Hull and Stationkeeping System	SurWM $V_{hub} = k_1 V_{10min,500-yr}$	SurSS $H_s = k_2 H_{s,500-yr}$	MIS, MUL	SurCM 500-yr Currents	SurWLR 500-yr Water Level

Notes:

- 1 (1 October 2015) ‘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
$H_{s,n-yr}$	significant wave height with a return period of n years
$H_{s,500-yr}$	significant wave height with a return period of 500 years
$V_{10min,n-yr}$	10 minute mean wind speed at hub height with a return period of n years
$V_{10min,500-yr}$	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

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 Installation and site conditions.

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

3 Wind Loads

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

3.1 Aerodynamic Loads Generated by the Rotor

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 Chapter 4, Section 2 are used in the definition of design load conditions in Chapter 5, Section 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. Reference is made 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 Chapter 9, Section 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 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/m³ (Slug/ft³)

C_s = shape coefficient (dimensionless)

A_{wind} = projected area of windage on a plane normal to the direction of the considered force, in m² (ft²)

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/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/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

<i>Shape</i>	<i>Values of C_s</i>
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 October 2015)

The wave forces acting on the Floating Offshore Wind Turbine Installation 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 Support Structure, high-frequency wave loads also need to be considered as they may excite the Floating Support Structure 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 Support Structure 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 (2007), Annex C and D. 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

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 Installations 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:

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

where

- $F_{current}$ = current force, in N (lbf)
- ρ_{water} = mass density of water, kg/m³ (Slug/ft³)
- C_D = drag coefficient in steady flow (dimensionless)
- $A_{current}$ = projected area exposed to current, in m² (ft²)
- 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

At locations where the Floating Offshore Wind Turbine Installation 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

For the Floating Offshore Wind Turbine Installation 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 Installation 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 Installation. 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

Ice loads acting on the Floating Offshore Wind Turbine Installation 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 Installation 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

SECTION 1	General Requirements	61
1	General	61
3	Wave-induced Motion Responses	62
5	Critical Global Loads and Responses.....	62
7	Air Gap (Deck Clearance or Freeboard).....	62
9	Model Testing	63
SECTION 2	Analysis Methodologies	64
1	General	64
3	Frequency Domain Analyses	64
5	Time Domain Analyses	65



CHAPTER 6 Global Performance Analysis

SECTION 1 General Requirements

1 General (1 October 2015)

Global performance analyses are to determine the global effects of environmental conditions and other loads on the Floating Offshore Wind Turbine Installation and its components including the tower, hull structure, 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 Chapter 5, Section 2.

Global performance analyses are intended to determine the following parameters:

- i) Motions of the Floating Support Structure 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 hull structure 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 Turbine Installations is provided in the *ABS Guidance Notes on Global Performance Analysis for Floating Offshore Wind Turbine Installations*. 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 Installation, provided that the distinctive load and response characteristics of the Floating Offshore Wind Turbine Installation are taken into account. The subjects that need special considerations include, but are not limited to, the following:

- i) Metocean data that have 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 Floating Support Structure, the stationkeeping system and the export electrical 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 Installation subjected to turbulent wind and irregular wave loading simultaneously

3 Wave-induced Motion Responses

The wave-induced response of the Floating Offshore Wind Turbine Installation 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 Support Structure, 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 Installation. 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 Installation 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 Support Structure 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

Stochastic methods for global performance analyses of the Floating Offshore Wind Turbine Installation 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 *MODU Rules* as well as API RP 2T.

7 Air Gap (Deck Clearance or Freeboard)

Unless topside deck structures, equipments 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 Support Structure 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 Support Structure. 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 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 Support Structure and waves.

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

- i) Motions of the Floating Support Structure 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 Support Structure

9 Model Testing

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 Installation 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 October 2015)

Because significant interactions could occur among the turbine RNA, the Floating Support Structure, the stationkeeping system and the export electrical cable, an integrated model (also termed “a coupled model”) including all 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 Support Structure 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 Turbine Installations 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 Installation. 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 has to be adequately validated against model tests or industry-recognized software.

3 Frequency Domain Analyses

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 Installation, 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 Support Structure, where second-order sum-frequency effects are determined to be significant, the high frequency springing responses of the Floating Support Structure 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 Installation.

Frequency-domain analyses, by nature, cannot capture nonlinear dynamic interactions among the components of the Floating Offshore Wind Turbine Installation. 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

The time domain analysis procedure consists of a numerical solution of the equations of motion for the Floating Offshore Wind Turbine Installation 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 Installation, 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 Floating Support Structure, 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 Support Structure, 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 TLP hull 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 Support Structure having Spar or single column TLP hull structures or other deep-draft hull structures are to be taken into account as appropriate.



CHAPTER 7 Design of Floating Support Structures

CONTENTS

SECTION 1	General Requirements	68
1	Overview	68
3	Format of Design Approach	68
5	Design Load Conditions	68
7	Design Life	68
9	Long-Term and Secondary Effects	69
11	Zones of Exposure	69
SECTION 2	Steel Structures	70
1	General	70
1.1	Materials	70
1.3	Corrosion Protection	70
1.5	Access for Inspection	70
3	Scantling Design of the Hull Structures	70
5	Structural Strength and Fatigue Analysis	70
7	Strength Design Criteria	71
7.1	General	71
7.3	Working Stress Design (WSD) Approach	71
7.5	Load and Resistance Factor Design (LRFD) Approach	73
9	Fatigue Assessment	73
11	Analysis and Design of Structures	74
11.1	Primary Structures	74
11.3	Other Major Structures	75
11.5	Local Structures	76
11.7	Guards and Rails	76
11.9	Vortex Shedding Strakes	76
11.11	Appurtenances	76
11.13	Temporary Structures	76
11.15	Protection of Deck Openings	76
13	Structural Connections	76
TABLE 1	Partial Safety Factors (γ_f) for Environmental Loads	73
TABLE 2	Safety Factors for Fatigue Life of Structures (Fatigue Design Factors [FDF])	74

SECTION 3	Concrete Structures.....	78
1	General	78
3	Loading Conditions	78
5	Strength Design Criteria.....	78
7	Fatigue Assessment	78



CHAPTER 7 Design of Floating Support Structures

SECTION 1 General Requirements

1 Overview

This Section provides general requirements to be applied in the design of the Floating Support Structure. The criteria in Chapter 7, Sections 2 and 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 1-1/9. General design considerations for the structures are provided in Chapter 3, Section 1.

3 Format of Design Approach

The Floating Support Structure can be considered as having three parts. The first is the buoyant hull, which in this Guide can be one of three types (i.e. Column-Stabilized, TLP or Spar-type, as defined in 1-1/15.1.1 through 1-1/15.1.3). 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 third major part of the Floating Support Structure is the RNA support structure including primarily the tower.

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

For an independent steel topside structure and the support structure of the RNA, the design criteria can be those specified in either 7-2/7.3 or 7-2/7.5, which are respectively the WSD and Load and Resistance Factor Design (LRFD) formatted criteria.

The design requirements for the concrete components of the Floating Support Structure are specified in Chapter 7, Section 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

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 Installation.

7 Design Life

The design life of the Floating Support Structure, which constitutes part of the Floating Offshore Wind Turbine Installation, 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

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 1-1/15.3.26. 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 Installation 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 Support Structures

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

Materials are to be protected from corrosion using a corrosion protection system including coatings. The system is to be effective from the time the Floating Support Structure 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

In the design of the Floating Support Structure, consideration is to be given to providing access for inspection during construction and, to the extent practicable, for survey after construction. Any openings on the Floating Support Structure 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

The steel structure of the Floating Support Structure 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 Installation.

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

The general guidance on choosing appropriate approaches to perform structural analyses for the Floating Support Structure 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/Table 1, where the ‘Type of Analysis’ column is denoted ‘S’.

7.3 Working Stress Design (WSD) Approach

When the strength design of the Floating Support Structure 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 Installation, as defined in 5-2/3.3 and 5-2/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

$$F_{allowable} = \text{allowable stress}$$

$$F_y = \text{specified minimum yield strength, as defined in the ABS Rules for Materials and Welding (Part 2)}$$

$$C_{SF} = \text{safety factor}$$

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

$$= 1.33$$

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

$$= 1.11$$

- For the temporary design conditions (designated ‘T’ in the column entitled ‘Safety Factor’ in 5-2/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

For an independent steel topside structure and the support structure of the RNA, 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/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, when they are combined with the design environmental loads. However, when 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. When 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/Table 1.

For design of tubular members and their connections (joints), resistance factors, member strength capacity equations and strength criteria are to be determined in accordance with API RP 2A-LRFD.

For structural members with other types of sections within the scope of the *AISC Steel Construction Manual* (LRFD part), resistance factors and member strength capacity equations are to be determined based on the relevant design requirements specified in that standard.

For the ultimate capacity of a flat plate or a cylindrical shell structure, reference is made to the *ABS Guide for Buckling and Ultimate Strength Assessment for Offshore Structures* or recognized industry standards. A minimum resistance factor of $1.05/\psi$, where the adjustment factor ψ is defined in 7-2/7.3.2, is to be applied. 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 October 2015)

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

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 Installation is in service and to those areas susceptible to corrosion-accelerated fatigue. **Guidance on the fatigue analysis of the Floating Support Structures is provided in Appendix 1.**

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 Installation times the safety factors for fatigue life (i.e., fatigue design factors (FDFs), as listed in 7-2/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/Table 1, where 'F' in the column titled 'Type of Analysis' designates the fatigue assessment. Loading history of the Floating Support Structure 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 October 2015)

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 (1 October 2015) 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

Structural analyses are to be performed to assess yielding, buckling and fatigue of the hull, the topside deck structure, the turbine tower 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 Support Structure.

11.1.2 Global Strength Analysis

The primary structural components of the hull, topside deck structure and turbine tower 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 Support Structure 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 Support Structure.

11.1.3 Major Joint Analysis – Analysis for Main Intersections of Primary Structures

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 Support Structure, the main intersections include connections of pontoon to pontoon, column to pontoon, column to topside deck structure, the tower to hull structure, and the tower to the RNA. For twin-pontoon Column-Stabilized Floating Support Structures, special attention is to be given to brace connections to braces, columns, pontoons, and topside deck structure.

For the Spar-type Floating Support Structure with truss connections, the main intersections include connections of top section to topside deck structure, truss to hull structure, the tower to hull structure, and the tower to the RNA. 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.

11.1.4 Fatigue Assessment

Fatigue assessment of the primary structures 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.

11.3 Other Major Structures

11.3.1 General

Depending on specific features of the Floating Support Structure, 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) Equipment/machinery support structures and their interface to the topside deck structure or the hull structure
- iii) Topside deck structural interface with deck modules, if relevant

11.3.2 Structural Interface with Equipment/Machinery Foundations or Deck Modules

The topside deck structure or the hull structure may require reinforcements to resist reaction forces from foundations of equipment/machinery, such as crane, export electrical 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 Support Structure 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

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 8-3/5 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 Support Structure.

11.3.4 Helicopter Deck

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

11.5 Local Structures

Structures that do not directly contribute to the overall strength of the Floating Support Structure (i.e., their loss or damage does not impair the structural integrity of the Floating Support Structure) 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

Guards and rails are to comply with the requirements of 5-3-1/5 of the *MODU Rules*, for application to the perimeters of the Floating Support Structure. 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

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 Support Structure. 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 *Steel Vessel Rules*.

13 Structural Connections

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 Support Structure 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 formation of voids in the grout.

Particulars of grouting mixtures used in the grouted connections are to be submitted for review.

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 Support Structures

SECTION 3 Concrete Structures

1 General

The general design guidance on structures constructed of reinforced and prestressed concrete is provided in the *ABS Guide for Building and Classing Gravity-based Offshore LNG Terminals*. The design considerations specific to the Floating Offshore Wind Turbine Installation are addressed in Chapter 7, Section 1 of this Guide and the following Subsections.

3 Loading Conditions

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 Chapter 5, Section 1, that are appropriate to the functions and operations of the Floating Offshore Wind Turbine Installation.

Load combinations are to reflect the design load conditions as specified in Chapter 5, Section 2 for the strength and fatigue analysis of the Floating Support Structure.

5 Strength Design Criteria

The partial safety factors (γ_p) for environmental loads are defined in 7-2/7.5.

7 Fatigue Assessment

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 Installation.



CHAPTER 8 Design of Stationkeeping Systems

CONTENTS

SECTION 1	General.....	81
1	General Design Requirements	81
3	Spread Mooring System	81
5	Single Point Mooring (SPM) System	82
5.1	CALM (Catenary Anchor Leg Mooring)	82
5.3	SALM (Single Anchor Leg Mooring)	82
5.5	Turret Mooring.....	82
7	Tendon System.....	82
9	Dynamic Positioning and Thruster Assisted Systems	82
11	Non-redundant Mooring Systems	82
SECTION 2	Design Conditions	83
1	Overview	83
3	Loading Conditions	83
3.1	Design Load Cases	83
3.3	Survival Load Cases	83
5	Design Conditions.....	83
5.1	Intact Condition	83
5.3	Damaged Condition with One Broken Line.....	83
5.5	Transient Condition with One Broken Line	84
7	Design Life	84
SECTION 3	Steel Mooring and Tendon Systems.....	85
1	Analysis Methods.....	85
3	Strength Criteria for Steel Mooring Lines and Tendons	85
5	Fatigue Criteria for Steel Mooring Lines and Tendons	86
7	Design of Components and Equipment	87
9	Corrosion and Wear.....	87
TABLE 1	Safety Factors for Steel Mooring Lines or Tendons	86
TABLE 2	Fatigue Design Factors (FDFs) for Fatigue Life of Steel Mooring Lines or Tendons	86
SECTION 4	Synthetic Fiber Ropes	89
1	Analysis Methods.....	89
3	Design Criteria	89
5	Design of Components and Equipment.....	89

SECTION 5	Anchor Holding Power	90
1	Drag Anchor	90
3	Vertically Loaded Drag Anchor (VLA)	91
5	Conventional Pile	91
7	Suction Pile	91
9	Suction Embedded Plate Anchor	92
11	Dynamically Installed Pile Anchor	92
13	Factor of Safety	92
TABLE 1	Coefficient of Friction of the Mooring Line on the Sea Floor	91
TABLE 2	Factor of Safety for Anchor Holding Capacities	93
SECTION 6	Field Test	94



CHAPTER 8 Design of Stationkeeping Systems

SECTION 1 General

1 General Design Requirements

Regardless of its type, the stationkeeping system is to be designed to

- i) Maintain the position of the Floating Support Structure within a specified limit from its reference position;
- ii) Control the directional heading of the Floating Support Structure 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 Support Structure 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, anchoring legs, etc., 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 Installation 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 Steel Vessel Rules* Section 4-3-5 for the stationkeeping system using a dynamic positioning system or a thruster assisted mooring system
- iv) *ABS FPI Rules* 5B-2/4 and *API RP 2T* for the tendon system

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 subject to special consideration by ABS.

3 Spread Mooring System

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 Support Structure 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

A single point mooring system allows the Floating Support Structure to weathervane. Three typical types of single point mooring systems are described below.

5.1 CALM (Catenary Anchor Leg Mooring)

A catenary anchor leg mooring system consists of a large buoy anchored by catenary mooring lines. The Floating Support Structure 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 Support Structure and the buoy.

5.3 SALM (Single Anchor Leg Mooring)

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 Support Structure is moored to the anchoring structure by soft hawser(s) or a rigid yoke arm.

5.5 Turret Mooring

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 Support Structure, allowing only angular movement of the Floating Support Structure relative to the turret so that the Floating Support Structure may weathervane. The turret may be mounted internally within the Floating Support Structure or externally. Typically, a spread mooring arrangement connects the turret to the sea floor.

7 Tendon System

A tendon system provides a vertical mooring system to the Floating Support Structure 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.

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 Dynamic Positioning and Thruster Assisted Systems

A dynamic positioning system is defined as all of the equipment necessary to provide a means of controlling the position and heading of the Floating Offshore Wind Turbine Installation within predetermined limits by means of vectored thrust.

A thruster-assisted system provides controlled thrust to assist the main mooring system and to reduce component loading of the main mooring system.

11 Non-redundant Mooring Systems (1 October 2015)

A non-redundant mooring system may be adopted in the design of the Floating Offshore Wind Turbine Installation. 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 Installation 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

This Section outlines loading conditions and design conditions to be applied in the design of the stationkeeping system of the Floating Offshore Wind Turbine Installation.

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

Intact Condition is the design condition of the stationkeeping system, where all components of the system are intact while the Floating Offshore Wind Turbine Installation is subjected to the design load cases.

5.3 Damaged Condition with One Broken Line

Damaged Condition is the design condition of the stationkeeping system, where any one of mooring lines or tendons is assumed to have been broken or removed, while the Floating Offshore Wind Turbine Installation is subjected to the design load cases associated with extreme design storm conditions. The Floating Support Structure 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 designer is to determine the worst scenario by analyzing several cases of broken line, including lead line broken and adjacent line broken cases.

Damaged Condition does not apply to a non-redundant stationkeeping system, for which an increased safety factor is required (see 8-3/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.

The loss of thruster power or mechanical failure of a thruster-assisted stationkeeping system will be considered on a case-by-case basis.

5.5 Transient Condition with One Broken Line

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 Support Structure 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 Support Structure and nearby structures or facilities is required. Global performance analyses for this transient condition subjected to the design load cases associated with extreme design storm conditions, as defined by DLC 6.2 in 5-2/Table 1, are to be performed. The effect of increased line tensions due to overshooting upon failure of one line (or thruster or propeller if mooring is power-assisted) are also to be considered.

Transient Condition does not apply to the non-redundant stationkeeping system.

7 Design Life

The design life of the stationkeeping system, which constitutes part of the Floating Offshore Wind Turbine Installation, 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

The Floating Offshore Wind Turbine Installation 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 Installation 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 Installation. The calculation of steady forces due to wind, current and wave are outlined in Chapter 5, Section 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

The steel mooring line or tendon is to be designed with the safety factors specified in 8-3/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/Table 1.

The safety factors in 8-3/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.

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)

<i>Loading Condition</i>	<i>Redundancy of the Stationkeeping System</i>	<i>Design Condition of the Stationkeeping System</i>	<i>Safety Factor</i>
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

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/Table 2.

The fatigue resistance of the mooring line or tendon is to be determined in accordance with 6-1-1/3 of the *FPI Rules*. 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/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

<i>Redundancy of the Stationkeeping System</i>	<i>Inspectable and Repairable</i>	<i>Fatigue Design Factors</i>
Redundant	Yes	2
	No	5
Non-redundant	Yes	3
	No	10

7 Design of Components and Equipment (1 October 2015)

Typical stationkeeping system components and equipment for the Floating Offshore Wind Turbine Installation 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 requirement is addressed in Chapter 8, Section 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* ABS Guide for the Certification of Offshore Mooring Chain
- *Single Point Mooring Equipment* ABS FPI Rules, Section 6-2-1
- *Winches and Windlasses* ABS MODU Rules, Section 3-4-1
- *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

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.

In general, the design load for the chain stopper, fairlead or tendon porch and its connection to the Floating Support Structure 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 Support Structure, 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/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 (1 October 2015)

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

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 Installation. The calculation of steady forces due to wind, wave and current are outlined in Chapter 5, Section 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

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 Installation 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/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

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 requirements specific to synthetic fiber ropes are 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 October 2015)

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 Chapter 8, Section 2. For an anchoring site with soft clay, 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 Chapter 8, Section 2. The safety factors for the holding capacity of a drag anchor are specified in 8-5/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.

TABLE 1
Coefficient of Friction of the Mooring Line on the Sea Floor

	<i>Coefficient of Friction, f</i>	
	<i>Static</i>	<i>Sliding</i>
Chain	1.00	0.70
Wire Rope	0.60	0.25

3 Vertically Loaded Drag Anchor (VLA)

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 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.

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 (1 October 2015)

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 the 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 October 2015)*

Suction embedded plate anchors and VLAs are both considered as plate anchors, which can be broadly categorized into drag embedded and direct embedded 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.

The safety factors for suction embedded plate anchors' holding capacity are specified in 8-5/Table 2.

11 Dynamically Installed Pile Anchor *(1 October 2015)*

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 particular 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 should in general not exceed 10% of the pile diameter or, if applicable, the equivalent pile diameter. In addition, the lateral deformation should in general not exceed 10% of the pile's main body width/diameter.

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.

13 Factor of Safety *(1 October 2015)*

The factors of safety for holding capacity of drag anchors, VLAs, and suction 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 October 2015)

<i>Loading Condition</i>	<i>Redundancy of the Stationkeeping System</i>	<i>Anchor Type</i>	<i>Design Condition of the Stationkeeping System</i>	<i>Safety Factor</i>
Design Load Cases	Redundant	Drag Anchors	Intact	1.5
			Damaged condition with one broken line	1.0
		Vertically Loaded Anchors (VLAs)	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

After the mooring system is deployed, each mooring line is in general required to be test loaded in accordance with Section 7.4.3 of API RP 2SK. For all types of anchors, the attainment of design-required minimum soil penetration depth is to be verified at the site.

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.

For pile anchors, the pile installation records are to be submitted for review. For suction piles, the pile installation records are to demonstrate the agreement between the calculated suction pressures and the suction pressure used to install the suction piles. For conventional piles, the pile installation records are to demonstrate the agreement between the calculated pile driving blow counts and the actual blow counts required to drive the piles to the design penetration.



CHAPTER 9 Stability and Watertight/Weathertight Integrity

CONTENTS

SECTION 1	General.....	96
1	Applicability	96
SECTION 2	Stability	97
1	General	97
3	Stability in Pre-Service Phases.....	97
1.1	Wet Tow	97
1.3	Installation and Commissioning.....	97
5	Stability in In-Service Phases	98
5.1	Intact Stability	98
5.3	Damage Stability	102
5.5	Overturning Moment.....	103
7	Weight Control	104
FIGURE 1	Intact Stability Curve for the RNA in Power Production.....	99
FIGURE 2	Intact Stability Curve for the Parked RNA.....	100
FIGURE 3	Capsize Criterion.....	101
FIGURE 4	Downflooding Criterion.....	102
SECTION 3	Watertight/Weathertight Integrity	105
1	General	105
3	Weathertight Integrity.....	105
5	Watertight Integrity.....	105
7	Penetrations	105



CHAPTER 9 Stability and Watertight/Weathertight Integrity

SECTION 1 General

1 Applicability

The Floating Offshore Wind Turbine Installation 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 Installation to be installed be contacted to obtain any further applicable criteria.



CHAPTER 9 Stability and Watertight/Weathertight Integrity

SECTION 2 Stability

1 General

The stability (righting stability) requirements specified in this Section are applicable to the Floating Support Structures with the hull types described in 1-1/15.1.1 through 1-1/15.1.3. Any unconventional stability issues that may be specific to an innovative configuration of the Floating Offshore Wind Turbine Installation 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 Support Structure 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 Support Structure, 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 Support Structure is to be assumed free of mooring restraints. However, detrimental effects of catenary mooring systems or of the thrusters for dynamically positioned installations are to be considered as appropriate.

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

During the installation and commissioning operations, the Floating Support Structure is to have a positive metacentric height. All relevant afloat conditions during installation or commissioning operations are to be considered.

If the Floating Support Structure 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 both the RNA and the Floating Support Structure 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

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 Support Structure 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 Installation 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

The intact stability of the Floating Support Structure carrying the RNA 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

The Floating Support Structure carrying the RNA 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/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/Table 1. An example overturning moment curve is depicted in 9-2/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.
- ii) The RNA is in the parked condition. Both the RNA and the Floating Support Structure are subjected to the extreme storm condition with a return period of 50 years (see DLC6.2 in 5-2/Table 1). An example overturning moment curve shown in 9-2/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. Both the RNA and the Floating Support Structure are subjected to the extreme storm condition with a return period of 1 year (see DLC7.1 in 5-2/Table 1). An example overturning moment curve is shown in 9-2/Figure 2.

The overturning moment is to be calculated in accordance with 9-2/5.5.

For the Spar-type Floating Support Structure, 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 Support Structure 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 Support Structure 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, the global performance requirement, or the design requirement of the stationkeeping system.

FIGURE 1
Intact Stability Curve for the RNA in Power Production

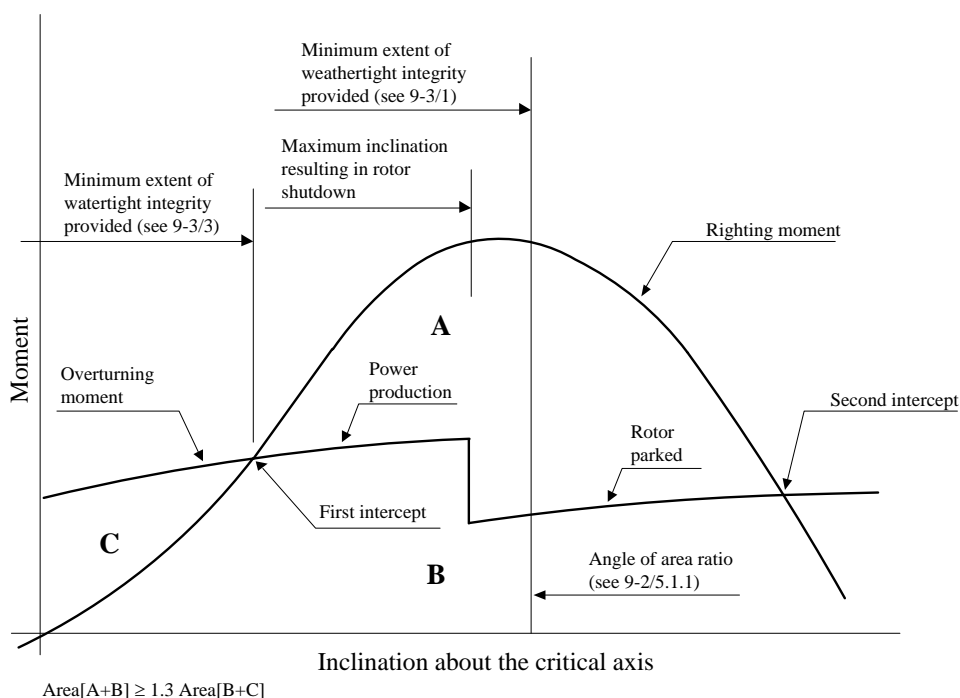
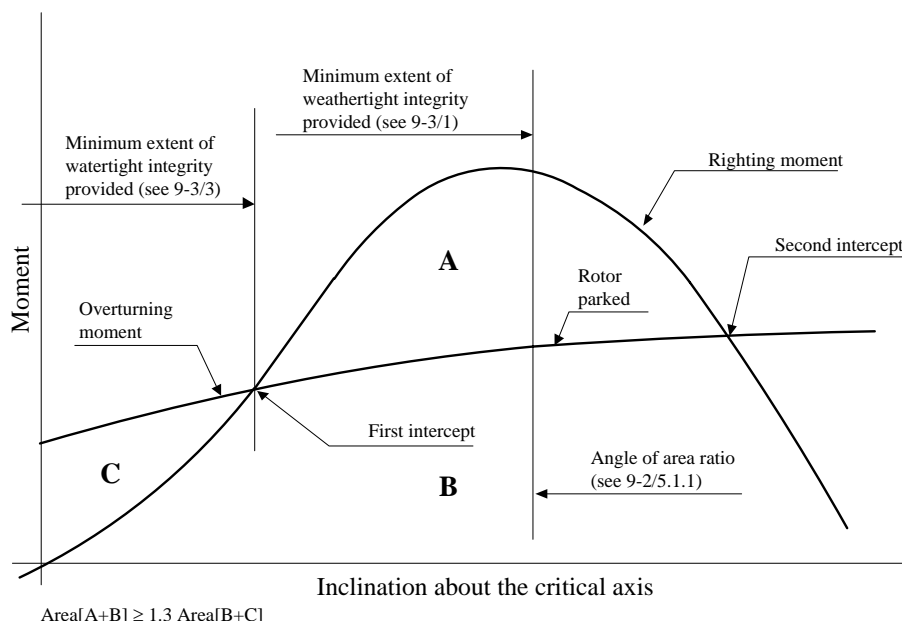


FIGURE 2
Intact Stability Curve for the Parked RNA



5.1.2 Dynamic-Response-Based Intact Stability Criteria

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 capsizes 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 Support Structure 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/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 capsizes 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.

The dynamic responses required as the input for the intact stability assessment include:

- For assessing the capsizes criterion, maximum heel angle (θ_{\max}) of the Floating Support Structure; and
- For assessing the downflooding criterion, maximum reduction in downflooding distance (*RDFD*) due to tilting of the Floating Support Structure and motions of the Floating Support Structure 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/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/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*. When comparably model test results are not available, model tests for a specific type of Floating Offshore Wind Turbine Installation 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

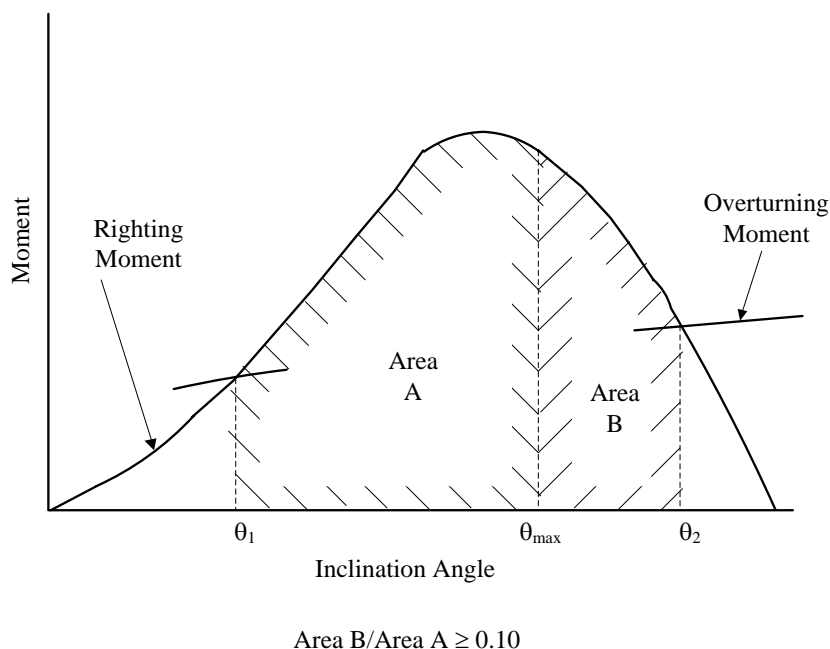
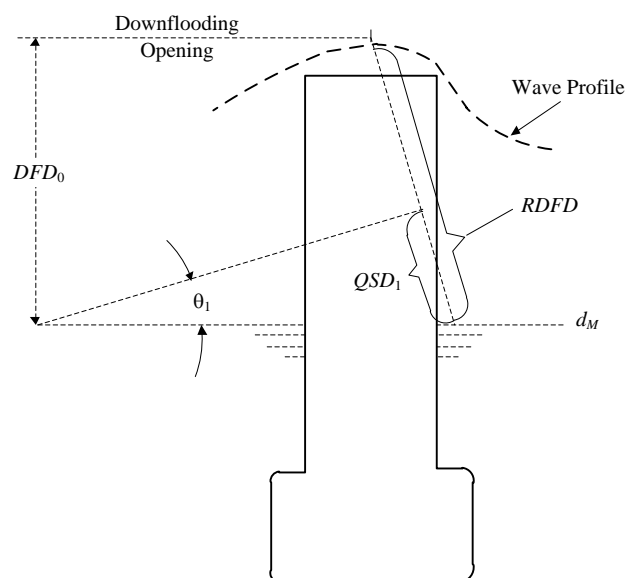


FIGURE 4
Downflooding Criterion



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

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 Support Structure, flooding in any one tendon compartment independently is also to be considered.

When 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) (1 October 2015) Documented procedures are in place addressing how to avoid progressive flooding, and outlining actions necessary to maintain the stability of the Floating Support Structure during repair operations offshore or during transit to a repair facility.

For the purpose of assessing damage stability, the overturning moment equivalent to the one exerted on the Floating Support Structure and the parked RNA subjected to the extreme storm condition with a return period of 1 year is to be considered. The overturning moment is to be calculated according to 9-2/5.5.

The final waterline of the damaged Floating Support Structure, which is assumed to sustain the one-compartment damage and subjected to the overturning moment described above for assessing the damage stability, is to satisfy the following criteria:

- i) Not to exceed the level to which watertight integrity is to be maintained as shown on the diagrams submitted in accordance with 1-1/9.5
- ii) Not to exceed the lowest point of the hull main deck or the top of the buoyant hull, whichever is lower
- iii) 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 Support Structure, 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

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 Installation, 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

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 Installation.

If the inclining test is conducted, it is required for one Floating Offshore Wind Turbine Installation 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 Installation, 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 Installation (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 can not 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 Support Structure, 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 1-1/9.5 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 1-1/9.5. For additional watertight integrity requirements, see 3-3-2/5.3 of the *MODU Rules*.

7 Penetrations

See 3-3-2/5.5 of the *MODU Rules*.



CHAPTER 10 Machinery, Equipment and Systems

CONTENTS

SECTION 1	Design Requirements.....	107
1	Machinery and Equipment	107
3	Marine Piping Systems	107
3.1	Bilge System.....	107
3.3	Ballast System	107
3.5	Vents and Sounds	108
5	Electrical Systems.....	108
7	Export Electrical Cable System.....	108
9	Fire Fighting Systems and Equipment.....	108
11	Safety Outfitting	108



CHAPTER 10 Machinery, Equipment and Systems

SECTION 1 Design Requirements

1 Machinery and Equipment

Machinery and equipment are in general to be in accordance with the applicable requirements of Part 4, Chapter 1 of the *MODU Rules*.

3 Marine Piping Systems

Marine piping systems are those systems that may be required for maintaining the normal operations of the Floating Offshore Wind Turbine Installation (such as power generation, bilge, ballast, tank venting and sounding, etc.). 4-2-1/3 of the *MODU Rules* provides the definitions of these systems.

Marine piping systems are to be in accordance with the requirements of the *MODU Rules*, except as modified in **this** Subsection.

3.1 Bilge System (1 October 2015)

The design of bilge systems is to meet the applicable requirements in Section 4-2-4 of the *MODU Rules*. If portable **power-driven** pumps are used **in lieu of a permanent bilge system**, **at least** two **such 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

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 *MODU 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

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 *MODU Rules*.

7 Export Electrical Cable System (1 October 2015)

The export electrical cable system connects the turbine RNA (or the electric power collection system) and the subsea electrical cable on the sea floor. It includes a section of the electrical cable that exports turbine generated electrical power and may also convey controls signals.

The export electrical cable system is usually connected to a certain location on the hull structure or the topside deck. Local support structure is to be designed for the maximum static and dynamic loading and in accordance with the requirements of 7-2/11.3.

Dynamic response of the suspended segment of the export electrical cable 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 5-2/3.5 for the stationkeeping system. The export electrical cable is to be designed to accommodate the maximum excursion of the Floating Support Structure subjected to those Design Load Cases.

The calculated fatigue life of the export electrical cable is not to be less than five (5) times the design life of the Floating Offshore Wind Turbine Installation. Anticipated fatigue damage accumulation due to reeling, handling, construction, and installation, as well as unplanned events such as partial recovery and reinstallation are to be considered. The procedures for reeling, handling, construction, and installation are to indicate the allowed cyclic loading that has been assumed in the design.

Additional design considerations, as applicable, are to be in accordance with recognized industrial standards such as API Specification 17 E and IEEE 1120.

9 Fire Fighting Systems and Equipment

Fire fighting systems and equipment are to be designed with consideration of the size, type and intended service of the Floating Offshore Wind Turbine Installation. As a minimum, portable extinguishers are to be provided in the quantities and locations in accordance with the applicable requirements in 5-2-4/Table 1 and 5-2-4/Table 2 of the *MODU 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 1-1/9.9.3.

Attention is drawn to the relevant requirements of the coastal State or other governmental authorities having jurisdiction over the Floating Offshore Wind Turbine Installation to be installed.

11 Safety Outfitting (1 October 2015)

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 Installation to be installed be contacted to obtain applicable requirements.



CHAPTER 11 Surveys

CONTENTS

SECTION 1	Surveys During Construction, Installation and Commissioning ...	111
1	General	111
3	Construction Surveys.....	111
3.1	Scope	111
3.3	Survey at Vendor's Shop	111
3.5	Structure Fabrication/Erection	111
3.7	Surveys on Steel Structures	112
3.9	Surveys on Concrete Structures.....	113
3.11	Piping Systems.....	115
3.13	Electrical Systems and Installations	115
3.15	Instrumentation and Control Systems	115
3.17	Mechanical Equipment and Systems	116
3.19	Fire and Safety Features	116
3.21	Stationkeeping System.....	116
5	Installation, Hook-up and Commissioning Surveys	116
5.1	Surveys During Installation and Hook-up	116
5.3	Commissioning Surveys.....	117
5.5	Personnel Safety	117
SECTION 2	Surveys After Installation and Commissioning	118
1	General	118
1.1	Notification and Availability for Survey.....	118
3	Surveys	118
3.1	Annual Survey	118
3.3	Special Periodical Survey.....	119
3.5	Continuous Survey Program	119
3.7	In-line Surveys and Timing of Surveys	119
5	Survey Reports File	120
7	Survey and Inspection Plan	120
9	Incomplete Surveys	120
11	Alterations	120
13	Damage and Repairs	120
15	Welding and Replacement of Materials	121
15.1	Ordinary and Higher Strength Structural Steels	121
15.3	Special Materials	121
15.5	Substitutions and Alterations	121
17	Corrosion Prevention System – Ballast Tanks	121
19	Requirements for Internal Examinations.....	121

21	Maintenance of Rotor-Nacelle Assembly (RNA).....	121
23	Survey for Extension of Use	121
25	Relocation of Existing Installations	122
27	Certification on Behalf of Coastal States	122
SECTION 3	Risk-based Surveys for Maintenance of Class	123
1	General	123
3	Certification on Behalf of Coastal States	123



CHAPTER 11 Surveys

SECTION 1 Surveys During Construction, Installation and Commissioning

1 General

This Section pertains to surveys and inspections during construction, installation and commissioning of the Floating Offshore Wind Turbine Installation. The documentation requirements for review are given in Chapter 1, Section 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.

3 Construction Surveys

3.1 Scope

This Subsection pertains to surveys and testing to be carried out during construction of the Floating Offshore Wind Turbine Installation at the builder's yard or facility.

3.3 Survey at Vendor's Shop

During construction of equipment components for a Floating Offshore Wind Turbine Installation, 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 required to have an effective quality system which is to be verified by the attending Surveyor.

3.5 Structure Fabrication/Erection

A quality control program compatible with the type and size of the planned Floating Offshore Wind Turbine Installation 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 his 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

The quality control program for the construction of the steel Floating Offshore Wind Turbine Installation 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

The items which are to be considered for each of the topics mentioned above are outlined in 11-2/3.7.2 through 11-2/3.7.10.

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

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. In the event that 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 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

Compartments which are designed to be permanently watertight or to be maintained watertight during installation are to be tested by a procedure approved by the attending Surveyor. The testing is also to be witnessed by the attending Surveyor.

3.7.10 Nondestructive Testing

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 of Hull Welds* 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.

Anchorage 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

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 Installation 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 *MODU 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

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 proven 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

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 Support Structure 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 October 2015)

For the Floating Support Structure 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 Support Structure
- 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 Support Structure
- Final field erection and leveling
- Pre-tensioning of mooring system
- Hook-up of piping, electrical, instrumentation and mechanical equipment

For the RNA and the export electrical cable, the Surveyor is to witness the installation of at least one (1) RNA per each type and the hook-up of the associated export electrical cable. Where there are more than fifty (50) RNAs of the same type, at least one **additional** RNA installation and export electrical cable **hook-up** per every fifty (50) turbines of the same type is to be witnessed by the Surveyor. The selection of RNA installations to be witnessed is to reflect having Surveys at the start and end of RNA installation periods and the rate of RNA installation within an installation period. The attending Surveyor is to verify that the RNAs to be installed are in compliance with relevant design documents for the Floating Offshore Wind Turbine Installation. Deviations from approved design documents and plans or any incidents such as damage or overstress to the Floating Support Structure or the stationkeeping system during the installation of the RNAs may require re-submittal of supporting documentation to provide an assessment of the significance of deviation and any necessary remedial actions to be taken.

5.3 Commissioning Surveys *(1 October 2015)*

The commissioning date will be the date on which the Surveyor issues the Interim Classification Certificate for the Floating Offshore Wind Turbine Installation. 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 Installation operating under various capacities and conditions.

The Surveyor is to witness the commissioning of at least one (1) RNA per each type. Where there are more than fifty (50) RNAs of the same type, the commissioning of at least one 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 Installation. Records of all these **performances** are to be maintained and made available to ABS.

5.5 Personnel Safety

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 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

This Section pertains to periodical surveys after installation and commissioning for the maintenance of classification of the Floating Offshore Wind Turbine Installation.

1.1 Notification and Availability for Survey

The Surveyor is to have access to the classed Floating Offshore Wind Turbine Installation at all reasonable times. The Owners or their representatives are to notify the Surveyor on all occasions when the Floating Offshore Wind Turbine Installation can be examined on site.

The Surveyor is to undertake all surveys on the classed Floating Offshore Wind Turbine Installation 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 Surveys

3.1 Annual Survey (1 October 2015)

An Annual Survey of the Floating Offshore Wind Turbine Installation 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 Installation 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 *MODU Rules*, where applicable, as follows:

- i) 7-2-4/1 for the Floating Support Structures
- ii) 7-2-4/3 for machinery, equipment and systems

The Annual Survey of the stationkeeping systems is to follow the applicable requirements in Section 7-2-4 of the *FPI Rules*.

3.3 Special Periodical Survey (1 October 2015)

A Special Periodical Survey of the Floating Offshore Wind Turbine Installation 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.

Underwater inspections, which can be considered as an alternative to the drydocking surveys, are to be carried out in accordance with Section 7-2-6 of the *MODU Rules*. A minimum of two underwater inspections are to be carried out during each five-year period of Special Periodical Survey. One such inspection is to be carried out in conjunction with the Special Periodical Survey. In all cases, the interval between any two underwater inspections is not to exceed three (3) years.

For further requirements of the Special Periodical Survey, refer to the *MODU Rules*, where applicable, as follows:

- i) 7-2-5/1 and 7-2-5/3 for the Floating Support Structures
- ii) 7-2-5/9 through 7-2-5/13 for machinery, equipment and systems

The Special Periodical Survey of the stationkeeping systems is to follow the applicable requirements in Section 7-2-6 of the *FPI Rules*.

3.5 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.

3.7 In-line Surveys and Timing of Surveys

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 thereon 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 Installation 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.

5 Survey Reports File

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 Survey and Inspection Plan, as required by 1-1/11.3
- 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, 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 Installation
- vii) Reports of thickness measurements of the Floating Support Structure
- viii) Reports of all NDT performed

7 Survey and Inspection Plan

The periodical surveys are to be carried out in accordance with the reviewed Survey and Inspection Plan to confirm that the Floating Offshore Wind Turbine Installation remains in compliance with the applicable classification requirements and other relevant standards. The Survey and Inspection Planning Document as required by 1-1/11.3 is to cover all surveys for the design life of the Floating Offshore Wind Turbine Installation.

9 Incomplete Surveys

When a survey is not completed, the Surveyor is to report immediately upon the work done in order that the Owners and ABS may be advised of the parts still to be surveyed.

11 Alterations

No alterations that affect or may affect classification are to be made to the classed Floating Offshore Wind Turbine Installation, 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 1-1-1/1 through 1-1-1/7 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 1-1-1/1 through 1-1-1/7 of the *ABS Rules for Conditions of Classification – Offshore Units and Structures (Part 1)*.

13 Damage and Repairs

If the Floating Offshore Wind Turbine Installation 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 Corrosion Prevention System – Ballast Tanks (1 October 2015)

Refer to 7-2-1/13 of the *FPI Rules* for the survey requirements for ballast tank corrosion prevention systems.

19 Requirements for Internal Examinations (1 October 2015)

Refer to 7-2-1/15 the *FPI Rules* for the survey requirements for internal spaces.

21 Maintenance of Rotor-Nacelle Assembly (RNA)

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 Installation.
- iii) All repair, modification and replacement have not altered values of RNA parameters specified in design documentation of the classed Floating Offshore Wind Turbine Installation.

23 Survey for Extension of Use

When an existing classed Floating Offshore Wind Turbine Installation 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 11-2/3.3 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 Installation.

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

An existing Floating Offshore Wind Turbine Installation 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 Chapter 11, Section 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

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 Installation. The plan is to be developed in accordance with the ABS *Guide for Surveys Using Risk-Based Inspection for the Offshore Industry* or the ABS *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques*.

3 Certification on Behalf of Coastal States

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 Installation 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 ensure 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 Chapter 11, Section 2.



APPENDIX 1 Fatigue Analysis of Floating Support Structures (1 October 2015)

CONTENTS

1	Introduction	125
3	Fatigue Analysis of the Hull Structure in the Low Frequency Range.....	125
5	Fatigue Analysis of the Hull Structure in the Wave Frequency Range.....	126
7	Fatigue Analysis of the Hull Structure in the High Frequency Range.....	126
9	Calculation of Fatigue Damage of the Hull Structure Subjected to Broadband Spectral Loading	127
11	Time-Domain Fatigue Analysis for the Heave Plate and the Tower	127



APPENDIX 1 Fatigue Analysis of Floating Support Structures

1 Introduction

Floating Offshore Wind Turbine Installations are subjected to complex loading conditions that involve environmental loads, in particular 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 Chapter 5, Section 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 Hull Structure in the Low Frequency Range

The wind and wave induced low-frequency motions depend on natural frequencies of rigid-body motions of the Floating Support Structure. 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 Support Structures, 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 Support Structure
- Bracing members connecting the columns and pontoons in a Column-Stabilized Floating Support Structure

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 Support Structures 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 Support Structure 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 hull structure 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 Hull Structure in the Wave Frequency Range

Wave-frequency responses of the Floating Support Structure subjected to wave forces are normally the major 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 hull structure subjected to wave forces and motions associated with a unit wave amplitude and various wave periods and directions.

7 Fatigue Analysis of the Hull Structure in the High Frequency Range

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 Support Structure, 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 hull structures due to high-frequency loads may be neglected for the Column-Stabilized or the Spar-type Floating Support Structure. For the TLP-type Floating Support Structure, high-frequency rigid-body motions of the hull structure 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 Support Structure 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 Support Structure, 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 Hull Structure Subjected to Broadband Spectral Loading

The Floating Offshore Wind Turbine Installation typically has broadband responses that do not follow the Rayleigh distribution. Fatigue damage of the Hull structure 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 Hull structure. 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

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 Installation. 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 Support Structure 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. There are substantial nonlinear hydrodynamic loads exerted on the heave plate due to the nonlinear viscous drag and relative hull motions. When 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, it assumes that 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.