



GUIDANCE NOTES ON

GLOBAL PERFORMANCE ANALYSIS FOR FLOATING OFFSHORE WIND TURBINE INSTALLATIONS

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American Bureau of Shipping
ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA**

Foreword

The Guidance Notes contained herein should be used in conjunction with the *ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations (FOWTI Guide)*.

These Guidance Notes provide suggested global performance analysis methodologies, modeling strategies and numerical simulation approaches for floating offshore wind turbines. These Guidance Notes do not set additional design requirements and criteria other than those specified in the *FOWTI Guide*, and should be used as a supporting document to the *FOWTI Guide*.

These Guidance Notes become 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 these Guidance Notes is the most current.

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

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CONTENTS

SECTION 1	Introduction	1
1	General	1
3	Applications.....	1
5	Terms and Definitions	1
5.1	Terminology.....	1
5.3	Abbreviations.....	6
7	References.....	6
 SECTION 2	 Characteristics of Floating Offshore Wind Turbines	 8
1	General	8
3	Floating Support Structures	8
3.1	TLP-Type Floating Support Structures	8
3.3	Spar-Type Floating Support Structures	9
3.5	Column-Stabilized (Semi-submersible) Floating Support Structures	10
3.7	Other Types of Floating Support Structures	10
5	Stationkeeping Systems	10
5.1	General.....	10
5.3	Catenary Moorings	11
5.5	Taut Moorings	11
5.7	Tendons	11
7	RNA and Control and Safety Systems.....	12
9	Coupling Effects.....	12
9.1	General.....	12
9.3	Aero-elastic Coupling	12
9.5	Aero-control Coupling.....	12
9.7	Tower-Hull and Mooring Coupling	12
9.9	Hull-Mooring Coupling.....	13
9.11	Other Coupling	13
 TABLE 1	 Representative Natural Periods of Typical FOWT Floating Support Structures	 8

SECTION 3 Modeling of Floating Offshore Wind Turbines..... 14

1	General	14
3	Modeling of the Hull	14
3.1	Hydrostatic Loads	14
3.3	Wave Loads on the Large-Volume Floating Hull	15
3.5	Wind Loads, Current Loads and Hull VIM.....	16
3.7	Instability.....	16
5	Modeling of Flexibility of Tower	16
7	Modeling of Stationkeeping System	16
7.1	General.....	16
7.3	Mooring Line Nonlinearity	17
7.5	Finite Element Analysis Approach	17
9	Modeling of Dynamics of Drive Trains	18
11	Modeling of Rotor Blade and Control and Safety Systems	18
11.1	General.....	18
11.3	Gravitational and Inertia Loads	18
11.5	Aerodynamic Loads	19
11.7	Actuation Loads (Operational Loads)	19
13	Modeling of Wind Farm Wake Effects	20
15	Electrical Cable Considerations	20

SECTION 4 Determination of Environmental Loads..... 21

1	General	21
3	Aerodynamic Loads on RNA.....	21
5	Typical Environmental Loads on Mooring Lines	21
5.1	Current Induced Loads	21
5.3	Ice-induced Loads	22
5.5	Vortex-induced Vibrations of the Mooring Lines	22
5.7	Direct Wave Loads on Mooring Lines	22
5.9	Marine Growth	22
7	Typical Environmental Loads on Floating Support Structures.....	22
7.1	Wind Loads.....	22
7.3	Wave Loads.....	23
7.5	Current Loads.....	23
7.7	Marine Growth	23
7.9	Vortex-Induced Motions (VIM) of the Floating Support Structure	24
7.11	Directional Distribution.....	24
9	Ice and Snow Accumulation Induced Loads.....	24
11	Earthquake Loads.....	24
13	Ice Loads.....	25

SECTION 5 Definition of Analysis Methodologies..... 26

1	Frequency-Domain and Time-Domain Analysis	26
1.1	Frequency-Domain Analysis	26
1.3	Time-Domain Analysis.....	26
1.5	Combined Time-Domain and Frequency-Domain Analysis	27

3	Quasi-Static and Dynamic Analysis	27
3.1	Quasi-Static Analysis	27
3.3	Dynamic Analysis	27
5	Coupled, Semi-Coupled, and Uncoupled Analysis	28
5.1	Coupled Analysis	28
5.3	Semi-Coupled Analysis	28
5.5	Uncoupled Analysis	28
SECTION 6	Global Motion Analysis	29
1	General	29
3	Static and Mean Responses	29
5	Low Frequency Motions	30
7	Wave Frequency Motions	30
9	High Frequency Motions	30
11	Tower and Turbine RNA Load Induced Vibrations	30
13	Damping	30
13.1	Damping of Low Frequency Motions	30
13.3	Damping of High Frequency Motions	31
15	Analysis Methods	31
15.1	Frequency-Domain Approach	31
15.3	Time-Domain Approach	32
15.5	Combined Time-Domain and Frequency-Domain Approach	32
SECTION 7	Air Gap Analysis	33
1	General	33
3	Air Gap Analysis Methods	33
3.1	Frequency-Domain Analysis	33
3.3	Time-Domain Analysis	33
3.5	Combined Time-Domain and Frequency-Domain Analysis	34
3.7	Other Considerations	34
SECTION 8	Mooring Strength Analysis	35
1	General	35
3	Mooring Strength Analysis Methods	35
3.1	Frequency-Domain Analyses for Spread Mooring Systems	36
3.3	Frequency-Domain Analyses for Single Point Mooring Systems	36
3.5	Time-Domain Analyses	36
3.7	Combined Time-Domain and Frequency-Domain Analyses	36
3.9	Maximum and Minimum Tendon Tensions	37
5	Suggested Time-Domain Analysis Procedure	37
7	Design Checks	37
9	Line Length and Geometry Constraints	37
11	Anchor Forces	38

SECTION 9	Mooring Fatigue Analysis	39
1	General	39
3	T-N Curve.....	40
5	Accumulated Fatigue Damage.....	40
7	Time-Domain Fatigue Analysis Method.....	41
9	Frequency-Domain Fatigue Analysis Method.....	41
11	Tendon Fatigue Analysis	41
13	Fatigue Design Checks.....	42
SECTION 10	Suggestions for Numerical Simulations.....	43
1	General	43
3	Time Step.....	43
5	Initial Transient Response	43
7	Wind Generation and Grid Size	44
9	Simulation of Wave Conditions	44
11	Flexibility of RNA and Tower.....	45
13	Simulation Length and Number of Random Seeds	45
15	Analysis Methods and Tools	47
TABLE 1	Adjustment of Wind Conditions with Different Averaging Time Durations.....	44
TABLE 2	Adjustment of the Significant Wave Height.....	45
TABLE 3	Suggested Minimum DOFs for Modeling Flexibility of the RNA and the Tower.....	45
TABLE 4	Suggested Simulation Time Duration and Number of Random Seeds for the DLCs	47
TABLE 5	Suggested Analysis Methods for the DLCs	48

SECTION 1 Introduction

1 General

Global performance analyses determine the global effects of environmental conditions and other loads on the Floating Offshore Wind Turbine (FOWT) and its components including the tower, hull structure, mooring lines or tendons, anchors, export electrical cable, etc. Global performance analyses should 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 of the *ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations (FOWTI Guide)*.

Because significant interactions could occur among the Rotor-Nacelle Assembly (RNA) and control system, the floating support structure and the stationkeeping system, an integrated ('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 are performed separately by using the responses of the floating support structure as boundary conditions, may also be acceptable, provided that the coupling effect of the stationkeeping system and the floating support structure is adequately taken into account.

The global performance analysis software should have the capability of considering complex interactions among aerodynamic loads, hydrodynamic loads, actions of turbine safety and control systems and structural dynamic responses of the FOWT. The analysis procedures should reflect the application limits of the selected software. Both publically available, industry-recognized software and in-house software may be used for the analyses. However, in-house software has to be adequately calibrated against model tests, field tests or the industry-recognized software.

General guidance on global performance analyses of the floating support structure and the stationkeeping systems can be found in:

- *ABS Rules for Building and Classing Floating Production Installations (FPI Rules)*, API RP 2T, API RP 2FPS and ISO 19904-1 for the design of floating offshore structures
- API RP 2SK, API RP 2SM and ISO 19901-7 for catenary mooring and taut leg mooring systems. API RP 2T for TLP tendon systems. References are also made to other appropriate ABS Rules, Guides and Guidance Notes such as those listed in Subsection 1/7.

3 Applications

These Guidance Notes provide global performance analysis methodologies, modeling strategies and suggestions for numerical simulations for FOWTs. These Guidance Notes do not set additional design requirements and criteria other than those specified in the *FOWTI Guide*, and should be used as a supporting document to the *FOWTI Guide*. The global performance analysis guidelines provided in these Guidance Notes are only applicable to FOWTs.

5 Terms and Definitions

5.1 Terminology

5.1.1 Added Mass

Effective addition to system mass, which is proportional to the mass of displaced water.

5.1.2 Air Gap

Clearance between the highest water surface that occurs during design environmental conditions and the lowest exposed structures not designed to withstand wave impingement.

5.1.3 Catenary Mooring

Mooring system where the restoring action is provided by the distributed weight of mooring lines.

5.1.4 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.

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

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

5.1.6 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.

5.1.7 Dip and Thrash Zone

A chain or wire rope section above and close to the seafloor that may touch the seabed due to the motions of the Floating Support Structure.

5.1.8 Dynamic Positioning (DP)

Stationkeeping technique primarily using a system of automatically controlled on-board thrusters to generate appropriate thrust vectors to counter the environmental actions and maintain an intended position within prescribed tolerances.

5.1.9 Emergency Shutdown

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

5.1.10 Floating Offshore Wind Turbine (FOWT)

Wind Turbine consisting of the Rotor-Nacelle Assembly (RNA), the Floating Support Structure and the Stationkeeping System.

5.1.11 Floating Offshore Wind Turbine Installation (FOWTI)

A Floating Offshore Wind Turbine Installation encompasses three principal areas: the Floating Support Structure (see 1/5.1.12) for carrying the wind turbine RNA (see 1/5.1.33), the Stationkeeping System (see 1/5.1.43) and the onboard machinery, equipment and systems that are not part of the RNA.

In these Guidance Notes, the Floating Offshore Wind Turbine Installation does not include the RNA.

5.1.12 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 1/5.1.48) and the Hull (see 1/5.1.15) structure.

5.1.13 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 TLP Tendons into the sea bed.

5.1.14 Gust

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

5.1.15 Hull

Combination of connected buoyant structural components such as columns, pontoons and intermediate structural braces; see also Monohull (see 1/5.1.23).

- 5.1.16 Hub Height**
Height of the center of the swept area of the wind turbine rotor above the Still Water Level.
- 5.1.17 Idling**
Condition of a wind turbine that is rotating slowly and not producing power.
- 5.1.18 Load**
External load applied to the structure (direct load) or an imposed deformation or acceleration (indirect load).
- 5.1.19 Load Effect**
Effect of a single load or combination of loads on a structural component or system, e.g. internal force, stress, strain, motion etc.
- 5.1.20 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 (see also 4-5/Figure 1 of the *FOWTI Guide*).
- 5.1.21 Mean Wind Speed**
Statistical mean value of the instantaneous wind speed over a specified time interval.
- 5.1.22 Minimum Breaking Strength (MBS)**
Certified strength of a chain, wire rope, fiber rope or accessories.
- 5.1.23 Monohull**
Floating structure consisting of a single, continuous, buoyant hull, and geometrically similar to an ocean-going ship or barge.
- 5.1.24 Mooring Components**
General class of components used in the Stationkeeping System.
- 5.1.25 Normal Shutdown**
Wind turbine shutdown operation in which all stages are under the control of the control system.
- 5.1.26 Offshore Wind Farm**
A group of wind turbines installed at an offshore site. An Offshore Wind Farm may also include other installations such as transformer/converter platforms, meteorological measurement facilities, electrical cables, accommodation units, etc.
- 5.1.27 Omni-directional (Wind, Waves or Currents)**
Acting in all directions.
- 5.1.28 Parked**
Condition of a wind turbine that is either in the Standstill or Idling condition, depending on the design of the wind turbine.
- 5.1.29 Pretension**
Tension applied to a mooring line or tendon when the Floating Support Structure at its static equilibrium position in mean still water and still air.
- 5.1.30 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.

5.1.31 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.

5.1.32 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.

5.1.33 Rotor-Nacelle Assembly (RNA)

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

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

5.1.34 Ringing

High frequency vertical vibration of the TLP spring-mass system excited by impulsive loading.

5.1.35 Semi-submersible

Floating structure normally consisting of a deck structure connected to submerged pontoons through a number of widely spaced, large cross-section supporting columns.

5.1.36 Set-down

Increase in the draft of a floating structure (for example, TLP) with the increase in the offset due to mooring or tendon system restraint.

5.1.37 Single Point Mooring

Mooring system that allows the floating structure to which it is connected to vary its heading (weathervane).

5.1.38 Spar

Deep-draft, small water-plane area floating structure.

5.1.39 Splash Zone

Part of the mooring lines or tendons of the Stationkeeping System 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.

5.1.40 Spread Mooring

Mooring system consisting of multiple mooring lines terminated at different locations on a floating structure and extending outwards, providing an almost constant heading to the Floating Support Structure.

5.1.41 Springing

High frequency vertical vibration of the TLP spring-mass system excited by cyclic loading at or near the TLP pitch or heave resonant periods.

5.1.42 Standstill

Condition of a wind turbine that is not rotating.

5.1.43 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.

5.1.44 Still Water Levels (SWL)

Abstract water levels used for the calculation of wave kinematics and wave crest elevation. See 4-5/Figure 1 of the ABS *FOWTI Guide*. Still Water Levels, which can be either above or below the Mean Sea Level, are calculated by adding to and subtracting from the effect of tide and surge on the Mean Sea Level.

5.1.45 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 within specified limits in response to environmental and other loading.

5.1.46 Tendon Connector

Device used to connect a tendon to the TLP Hull (top connector) or to the foundation template (bottom connector).

5.1.47 Tension Leg

A collective group of tendons associated with one column of the platform.

5.1.48 Tower

The structural component or assembly that connects the Hull structure to the Rotor-Nacelle Assembly.

5.1.49 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.

5.1.50 Taut-line Mooring

Mooring system where the restoring action is provided by elastic deformation of mooring lines.

5.1.51 Thruster-assisted Mooring

Stationkeeping system consisting of mooring lines and thrusters.

5.1.52 Tropical Cyclone (Hurricane, Typhoon)

A tropical storm with sustained wind speeds in excess of 33 m/s (64 knots or 74 mph). Such a storm is called a hurricane, typhoon, or cyclone based on the storm location. For example, tropical cyclones are typically referred to as hurricanes in the Gulf of Mexico and North Atlantic, while in the South China Sea and Northwest Pacific they are called typhoons. In the South Pacific and South Indian Ocean, however, they are commonly referred to as cyclones.

5.1.53 Uni-directional (Wind, Waves or Currents)

Acting in a single directions.

5.1.54 Vortex Induced Motion (VIM)

The motion of the Hull structure induced by vortex when the hull is exposed to a current.

5.1.55 Vortex Induced Vibration (VIV)

A phenomenon of the vibration of cylindrical structures exposed to a current. Cylindrical structures exposed to a current may create alternating eddies, or vortices, at a regular period. The eddies create alternating lift and drag forces on the cylinder. When a natural period of a structure falls close to the period of vortex shedding, oscillations of the structure can occur.

5.1.56 Water Depth

Vertical distance between the sea floor and the Still Water Level.

5.1.57 Wind Profile (Wind Shear Law)

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

5.1.58 Weathervaning

Process by which a floating support structure passively varies its heading in response to time-varying environmental actions.

5.1.59 Yawing

Rotation of the rotor axis about a vertical axis for horizontal axis wind turbines.

5.1.60 Yaw Misalignment

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

5.3 Abbreviations

ABS	American Bureau of Shipping
API	American Petroleum Institute
BEM	Blade Element Momentum method
DOF	Degree Of Freedom
FE(M)	Finite Element (Method)
FOWT	Floating Offshore Wind Turbine
FOWTI	Floating Offshore Wind Turbine Installation
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
QTF	Quadratic Transfer Function
RAO	Response Amplitude Operator
RNA	Rotor-Nacelle Assembly
TLP	Tension Leg Platform
VIM	Vortex Induced Motion
VIV	Vortex Induced Vibration

7 References

- i) ABS *Guide for Building and Classing Floating Offshore Wind Turbine Installations (FOWTI Guide)*
- ii) ABS *Rules for Building and Classing Floating Production Installations (FPI Rules)*
- iii) ABS *Rules for Building and Classing Mobile Offshore Drilling Units (MODU Rules)*
- iv) ABS *Rules for Building and Classing Single Point Moorings (SPM Rules)*
- v) ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*
- vi) API RP 2FPS, *Recommended Practice for Planning, Designing, and Constructing Floating Production Systems*
- vii) API RP 2N, *Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions*
- viii) API RP 2SK, *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures*
- ix) API RP 2SM, *Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring*

- x) API RP 2T, *Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*
- xi) IEC 61400-1, *Wind Turbines – Part 1: Design Requirements*
- xii) IEC 61400-3, *Wind Turbines – Part 3: Design Requirements for Offshore Wind Turbines*
- xiii) ISO 19901-7, *Petroleum and natural gas industries – Specific Requirements for Offshore Structures, Part 7: Stationkeeping Systems for Floating Offshore Structures and Mobile Offshore Units*
- xiv) ISO 19904-1, *Petroleum and natural gas industries – Floating Offshore Structures, Part 1: Monohulls, Semi-submersibles and Spars*
- xv) ISO 19906, *Petroleum and natural gas industries – Arctic Offshore Structures*

SECTION 2 Characteristics of Floating Offshore Wind Turbines

1 General

An FOWT consists of a number of main subsystems including the floating support structure (hull structure and tower), the turbine RNA and safety and control system, as well as the stationkeeping system including mooring (or tendon) system and anchoring systems. This section describes the key issues and characteristics of the main FOWT subsystems relevant to global performance analyses. Representative coupling effects between the components of the FOWT are also identified.

3 Floating Support Structures

The floating support structure consists of the hull structure and the tower. A common feature of the differing types of hull structures is that they utilize excess buoyancy to support the tower and the RNA and to provide mooring (or tendon) system tension. For this reason, the design of the floating support structure tends to be weight sensitive.

Depending on specific site conditions, ocean waves typically contain first-order energy in the range 3 to 30s. For the floating support structure, the natural periods of different modes of motion are of primary interest and, to a large extent, reflect the design philosophy. Typical motion natural periods of different types of floating support structure are summarized in Section 2, Table 1.

TABLE 1
Representative Natural Periods of Typical FOWT Floating Support Structures

<i>Motions</i>	<i>Natural Periods (seconds)</i>		
	<i>Spar-Type</i>	<i>Semi-submersible-Type</i>	<i>TLP-Type</i>
Surge	>40	>40	>40
Sway	>40	>40	>40
Heave	20-50	17-40	<5
Roll	25-60	25-50	<5
Pitch	25-60	25-50	<5
Yaw	>3	>3	>3

3.1 TLP-Type Floating Support Structures

A TLP-type floating support structure is a vertically moored, buoyant structural system wherein the excess buoyancy of the hull maintains tension in the stationkeeping system.

A TLP-type floating support structure consists of the structural components of the 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.

The TLP-type floating support structure differs fundamentally from the other floating structure concepts, mostly because of the following reasons:

- Tendon stiffness, rather than the ‘water-plane’ stiffness, governs the vertical motions.
- It is normally weight sensitive.
- It has low restraint to horizontal motions (surge, sway and yaw), but is highly restrained in the vertical direction (heave, roll and pitch).
- Higher order wave forces at different sum-frequencies may introduce resonant (springing) or transient (ringing) responses in the vertical direction. These effects may significantly increase tendon loads.
- Restrained by the tendon system, the TLP-type floating support structure moves along a spherical surface. This gives rise to the set-down effect, which is a kinematic coupling between the horizontal surge/sway motions and the vertical heave motion. The magnitude of the set-down affects the wave air-gap, tendon forces and electrical cable responses.

The TLP-type floating support structure generally experiences horizontal wave frequency motions of the same order of magnitude as those of a semi-submersible of comparable size. On the other hand, the TLP-type floating support structure behaves like a fixed structure with practically no wave frequency vertical motion responses, because the wave frequency forces are counteracted by the stiffness of the tendon system.

The flexibility of the tower could have significant influences on the natural periods of roll and pitch motions of the TLP-type floating support structure. The high frequency loads due to the rotor rotations and aeroelastic responses of the RNA and the tower could introduce resonant and/or transient responses in the vertical motions, which could significantly increase the tendon loads.

3.3 Spar-Type Floating Support Structures

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. The fixed ballast tank provides temporary buoyancy during a horizontal wet tow and provides the needed ballast in upending by flooding the tank. After upending, the ballast water may be replaced by fixed ballast (a substance with a density higher than water) to lower the Spar’s center of gravity. The ballast in the fixed ballast tank results in a vertical center of gravity well below the center of buoyancy, which provides the Spar with sound stability, as well as desired motion characteristics. The flotation tank is located adjacent to the fixed ballast tank to provide additional buoyancy for wet tow and ballast in upending.

With a deep draft, the Spar-type floating support structure has a large area exposed to current forces, which is usually the dominant mean force on a Spar. Low frequency vortex induced oscillations may increase the effective drag leading to even higher mean current forces. By installing strakes on the Spar hull, the vortex induced cross-flow oscillation can be mitigated. However, the strakes increase the added mass and the drag forces on the Spar.

The Spar-type floating support structure is usually compliant to surge, sway, heave, roll, pitch, and yaw motions. The natural periods of motions in all six degrees of freedom are usually outside the range of wave periods. In addition, the Spar-type floating support structure has a low level of vertical wave excitation due to its large draft, which exploits the fact that the first order wave motions and dynamic pressures decay exponentially with depth. These result in very small heave motions.

Due to relatively small wave frequency motions, the Spar-type floating support structure is generally not subjected to large dynamic mooring line forces, although their actual effect has to be evaluated by considering the actual location of the fairlead and the increase in horizontal wave frequency motion towards the waterline.

The mooring system for the Spar-type floating support structure can be in the form of catenary moorings, semi-taut-line moorings or taut-line moorings. The motions and mooring loads of the catenary moored Spar-type floating support structure are normally insensitive to the high frequency loads generated by the rotor rotations and aeroelastic responses of the RNA and the tower.

Since the Spar-type floating support structure has a slender hull in the vertical direction and the mooring system tends to have relatively low yaw stiffness, the Spar-type FOWT may experience yaw instability which should be avoided.

3.5 Column-Stabilized (Semi-submersible) Floating Support Structures

A column-stabilized floating support structure, also known as the Semi-submersible 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. The tower may be connected directly to a column or caisson or to the topside structure.

Current forces could be significant on column-stabilized floating support structure due to the bluff shapes of their underwater columns and pontoons.

The column-stabilized floating support structure is characterized by having free modes of motion, which means that all natural periods of motion are outside the range of energetic wave periods. However, the wave frequency motions of the column-stabilized floating support structure may be significant, especially in extreme environmental conditions.

For the column-stabilized floating support structure, wave impact underneath the deck due to insufficient air-gap may influence the global motions and local structural responses.

The spread mooring system in the form of the catenary, semi-taut lines or taut lines is normally adopted as the stationkeeping system for the column-stabilized floating support structure. The column-stabilized floating support structure with the catenary mooring system may experience significant dynamic mooring loads due to the wave frequency responses. The motions and mooring loads of the catenary moored column-stabilized floating support structure are normally insensitive to the high frequency loads generated by the rotor rotations and aeroelastic responses of the RNA and the tower.

3.7 Other Types of Floating Support Structures

For the floating support structure having a hull configuration or a hull-mooring combination that does not belong to the those described above, general guidance may be found in ABS *FPI Rules*, API RP 2T, API RP 2FPS, ISO 19904-1, API RP 2SK and ISO 19901-7, as well as other appropriate ABS Rules, Guides and Guidance Notes for the design of floating offshore structures (see 1/7).

5 Stationkeeping Systems

5.1 General

An FOWT stationkeeping system is primarily designed to keep the FOWT within its position tolerances. It is also required to assist in achieving motion limits imposed by operational requirements of the RNA. Because the turbine RNA could exert large yaw moments to the floating support structure that normally has small yaw stiffness, the stationkeeping system may also need to be designed to provide sufficient yaw stiffness to mitigate the FOWT yaw motions.

A stationkeeping system includes a mooring (tendon) system and an anchoring system. The mooring system provides resistance to environmental loading by mobilizing reaction forces as the result of the gross change in mooring geometry. It essentially works as a collection of spring mechanisms where displacements of the floating support structure from its neutral equilibrium position introduce restoring forces to react to the applied loading. Each mooring line acts as a tension spring and provides its intended functions through one of the following two mechanisms:

- Hanging catenary effect due to gravity acting vertically on the mooring line
- Line elastic effect due to elastic stretch over the length of the mooring line

When FOWTs are expected to be deployed in relatively shallow water, in order for the mooring systems to have the required stiffness, fiber ropes, clump weights and buoys may be used in addition to chains and wire ropes.

5.3 Catenary Moorings

The geometry of catenary moorings is related to the following parameters:

- Submerged weight of the suspended lines
- Horizontal mooring load
- Line tension
- Line slope at fairlead

The compliance of the catenary mooring line allowing for wave-induced floating support structure motions is provided by a combination of geometrical change and axial elasticity of the lines. Large line geometrical changes could lead to significant dynamic responses in the catenary mooring system due to the large transverse drag loads.

The mooring lines in a catenary mooring system are commonly composed of steel rope and chain segments. If necessary, clump weights and buoys may be used to achieve desired line configurations.

5.5 Taut Moorings

In a taut mooring system, the mooring lines are nearly straight between the anchor and the fairlead and an uplift force is exerted on the anchor. The compliance of the mooring line allowing for wave-induced floating support structure motions is provided mainly by line elasticity.

Transverse geometric changes in a taut mooring system are typically much smaller than those in a catenary mooring system. Therefore, dynamic effects due to line drag loads are moderate.

Synthetic ropes have been used as mooring lines in taut mooring systems to provide required stiffness and low weight. Compared to steel ropes, synthetic ropes exhibit more complex stiffness characteristics (e.g., hysteresis), which may significantly alter dynamic effects (see the ABS *Guidance Notes on the Application of Fiber Rope for Offshore Mooring*).

5.7 Tendons

The TLP tendons are the vertical mooring lines similar to those in taut mooring systems. The main difference is that tendons are traditionally made of tubes that are hardly compliant in the axial direction. The TLP tendon system acts as an inverted pendulum, where the stationkeeping capacity is governed by tendon length and pretension.

By restraining the FOWT at a draft deeper than what is required to balance its weight, the tendons are typically under a continuous tensile load that provides a horizontal restoring force when the hull is displaced laterally from its equilibrium position. With very high stiffness in the axial direction, the tendon system limits heave, pitch, and roll responses of the hull to small amplitudes while its relatively compliant transverse restraints can be designed to achieve surge, sway, and yaw responses within operationally acceptable limits.

The tendons may take one of several forms, for example:

- *Tubular Members with Threaded or other Mechanical Connectors.* These members may be designed to be completely void, partially void, or fully flooded. The tubular member and the connectors may be fabricated as one piece, or assembled from separate tubular segments that are joined with threaded connectors. The tendon components may be made of metal or fiber reinforced composites, with either integral or metallic connectors.
- *Tubular or Solid Rod Members with Welded Connections.* The tubular members are fabricated from seamless or rolled and welded steel and are designed to be welded together, prior to or during offshore installation, to form a continuous tendon element.
- *Tendon Strands.* These tendons are fabricated from small diameter high tensile strength wire or fiber strands and are formed into bundles. These tendons are designed to be installed offshore using a continuous one-piece spooling operation to minimize the need for intermediate connectors.