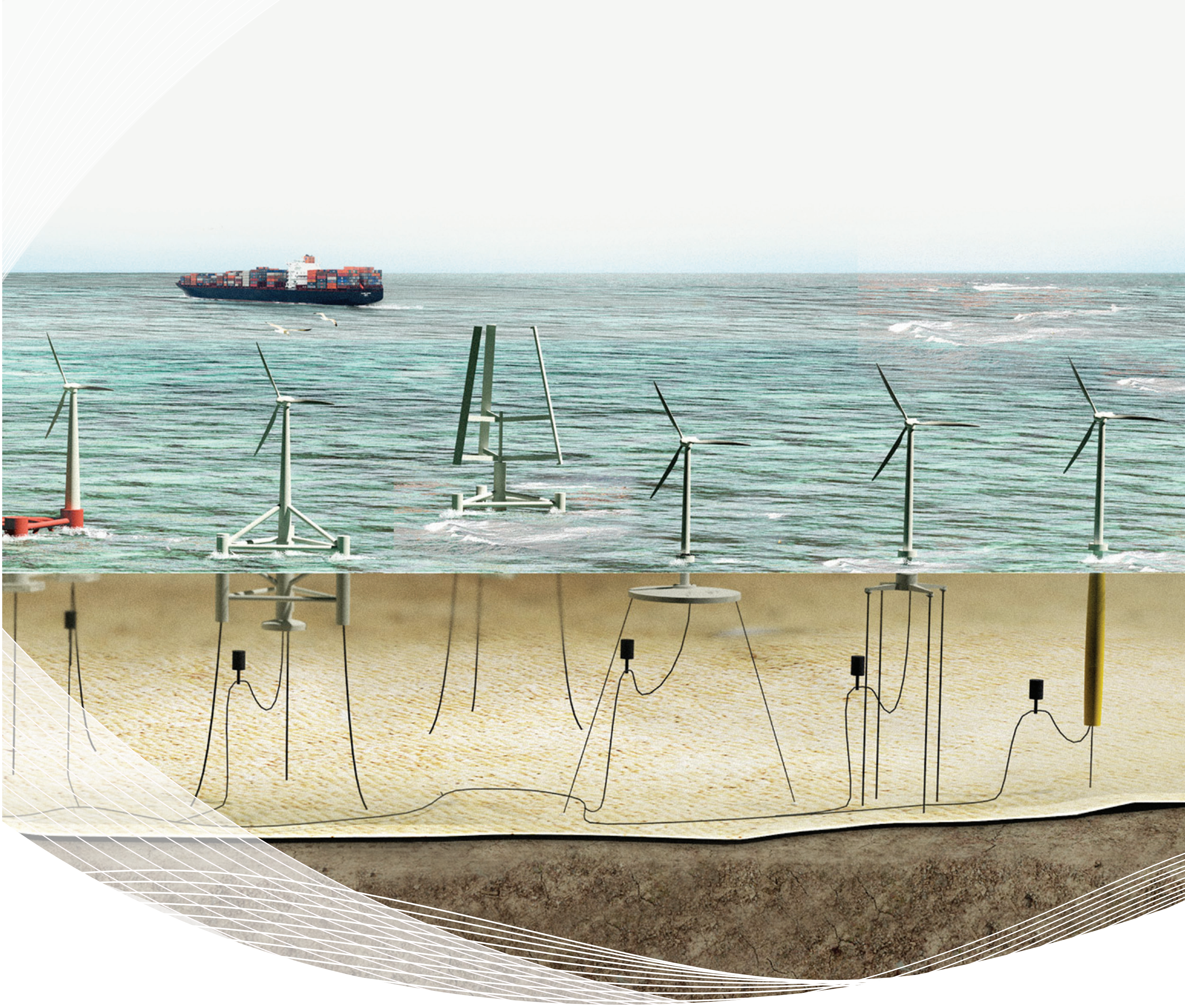
Classification and Certification of Floating Offshore Wind Turbines



October 2015
NI 572 DT R01 E

Guidance Note

Classification and Certification of Floating Offshore Wind Turbines

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MARINE & OFFSHORE DIVISION
GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine & Offshore Division (the "Society") is the classification (" Classification ") of any ship or vessel or offshore unit or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- "prepares and publishes Rules for classification, Guidance Notes and other documents (" Rules ");
- "issues Certificates, Attestations and Reports following its interventions (" Certificates ");
- "publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as " Certification ".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as " Services ". The party and/or its representative requesting the services is hereinafter referred to as the " Client ". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisement given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisement is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - **It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisement or cause to modify its scope.**

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out.

ARTICLE 3

3.1. - **The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are a collection of minimum requirements but not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.**

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - **The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.**

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - **The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.**

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- "reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- "conducts surveys at the place of their construction;
- "classes Units and enters their class in its Register;
- "surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - **The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.**

5.2. - **The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.**

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - **The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder.**

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - **If the Services of the Society or their omission cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee. These limits apply regardless of fault including breach of contract, breach of warranty, tort, strict liability, breach of statute, etc.**

The Society bears no liability for indirect or consequential loss whether arising naturally or not as a consequence of the Services or their omission such as loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - **Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.**

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - **Overdue amounts are increased as of right by interest in accordance with the applicable legislation.**

8.3. - **The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.**

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- "Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit ;
- "copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- "the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, may be passed on to IACS (International Association of Classification Societies) according to the association working rules;
- "the certificates, documents and information relative to the Units classed with the Society may be reviewed during certificating bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France, or to another Court as deemed fit by the Society.

12.3. - **Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.**

ARTICLE 13

13.1. - **These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement. They are not varied by any purchase order or other document of the Client serving similar purpose.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.

GUIDANCE NOTE NI 572

NI 572

Classification and Certification of Floating Offshore Wind Turbines

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October 2015

Section 1 General

Section 2 Material

Section 3 Design Conditions and Loads

Section 4 Stability

Section 5 Structure Design

Section 6 Structural Analysis

Section 7 Scantling

Section 8 Station Keeping

Section 9 Foundation

Section 10 Marine Systems

Appendix 1 Life Cycle

Appendix 2 Hydrodynamic

Appendix 3 External Conditions

SECTION 1 GENERAL

1 General

1.1 Application

1.1.1 This Guidance Note provides specific guidance and recommendations for the classification and certification of Floating platforms designed as support of Floating Offshore Wind Turbine (FOWT).

Note 1: Requirements and recommendations of this Guidance Note may be applied in compliance to requirements from the IEC 61400 series standards.

1.1.2 This Guidance Note is intended to cover floating platforms supporting single or multiple turbines with horizontal or vertical axis.

1.1.3 This Note does not cover top structure, i.e. tower, rotor, blades and nacelle design (their influence on floating platform and mooring system is however considered).

1.1.4 In general, FOWT can be considered as unmanned structures.

1.2 Documents

1.2.1 Recognized standards

This Guidance Note makes reference to recognized International Standards, as given in Tab 1.

1.2.2 Other Standards

Technical Standards, other than those stated in Tab 1, may be used for the purpose of certification on a case-by-case basis, upon the acceptance of the Society.

1.2.3 Combined use of technical Standards

The full list of standards which are specified and used for a given project are to be submitted to the Society before the review of certification documents is started.

The Society will give a particular attention to combined use of technical standards, when technical requirements from different standards are mixed together.

Note 1: Attention is drawn to compliance with possible national regulations which may not allow the mix of different Standards.

1.2.4 Society documents

The Society documents listed in Tab 2 are referred to in this Note.

1.3 Floating platforms

1.3.1 Four categories of floating platforms are considered in this Note:

- Column Stabilized Units:

  When the FOWT is a column stabilized unit, general guidance may be found in NR571

Note 1: Semi submersible units are part of Column Stabilized units.

- SPAR platform: Ballast floating platforms that achieve stability by using ballast weights placed below a global buoyancy center, which creates a righting moment and high inertial resistance to pitch and roll and usually enough draft to offset heave motion
- TLP: Tension Leg Platforms (TLP), that achieve stability through the use of tendons

  When the FOWT is a Tension Leg Platform, general guidance are given in the NR578
- Barge (ship shape platform): Buoyancy floating platforms, that achieve stability by the use of distributed buoyancy, taking advantage of weighted water plane area for righting moment.

  When the FOWT is a ship shape platform, general guidance is given in Offshore Rules.

Any other type of floating platform is to be considered by the Society on a case by case basis.

1.4 Station keeping systems

1.4.1 The following station keeping systems are considered:

- Catenary mooring system
- Taut mooring system
- Tendon system (Tension Leg).

2 Definitions

2.1 General

2.1.1 Administration

Administration means the Government of the State responsible for or managing the area in which the floating offshore wind turbine is operating.

2.1.2 Owner

Owner means the Registered Owner or the Disponent Owner or the Manager or any other party having the responsibility to keep the floating offshore wind turbine seaworthy, having particular regard to the provisions relating to the maintenance of class or certificate.

2.1.3 Approval

Approval means the review by the Society of documents, procedures or other items related to classification / certification, verifying solely their compliance with the relevant Rules requirements, or other referential where requested. The reviewed plans and documents receive a formal approval with or without comments.

2.2 Technical definitions

2.2.1 Floating Offshore Wind Turbine (FOWT)

The FOWT means an electricity production unit using wind power, installed on a floating support, located off the coast.

The main components of the FOWT (see Fig 1) are:

- top structure including the rotor-nacelle assembly (RNA) and the tower
- sub-structure, including the floating structure and its mooring system (or tendons)
- foundation.

Axes of the FOWT are defined as given in Fig 2.

2.2.2 Top-structure

The tower and the RNA constitute together the top-structure of the FOWT.

2.2.3 Sub-structure

The floating structure and its station keeping system constitute together the sub-structure of the FOWT.

Table 1 : Recognized Standards

Standard	Title	Main interest
ISO 19900	Petroleum and natural gas industries - General requirements for offshore structures	General requirements applicable for offshore floaters
ISO 19901	Petroleum and natural gas industries - Specific requirements for offshore structures	Specific requirements applicable for offshore floaters
ISO 19901-1	Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations	Specific requirements for metocean design for offshore structures
ISO 19901-2	Petroleum and natural gas industries — Specific requirements for offshore structures — Part 2: Seismic design procedures and criteria	Specific requirements on seismic design procedures and criteria
ISO 19901-4	Petroleum and natural gas industries — Specific requirements for offshore structures — Part 4: Geotechnical and foundation design considerations	Specific requirements for geotechnical and foundation design for offshore structures
ISO 19903	Petroleum and natural gas industries — Fixed concrete offshore structures	Concrete requirements
ISO 19904	Petroleum and natural gas industries — Floating offshore structures	Requirements and guidance for the structural design and/or assessment of floating offshore platform
ISO 2394	General principles on reliability for structures	Principles of structural assessment
EN 1993-1	Eurocode 3: Design of steel structures	General rules and rules for Buildings
IEC 61400-3	Wind Turbines - Design requirements for offshore wind turbines	Design requirement applicable for offshore wind turbines
IEC 61400-22	Wind Turbines - Conformity testing and certification	Certification scheme for wind turbines
IEC 61400-1	Wind Turbines - Design requirements	Design requirements for wind turbines
API RP 2A LRFD	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-Load and Resistance Factor Design	Design and construction of offshore fixed platform
API RP 2A WSD	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-Working Stress Design	Design and construction of offshore fixed platform
API RP 2T	Recommended Practice for Planning, Designing and Constructing Tension Leg Platforms	Design of a Tension Leg Platform system
AISC	American Institute of Steel Construction Specifications for the Design, Fabrication and Erection of Structural Steel Buildings	Steel Construction Manual
IMO MSC 267(85)	International Code on Intact Stability (IS Code 2008)	General requirements for stability
Eurocode 2	Design of concrete structures	Concrete structure requirements
EN 206	Concrete - Specification, performance, production and conformity	Concrete specifications

Figure 1 : Floating offshore wind turbine

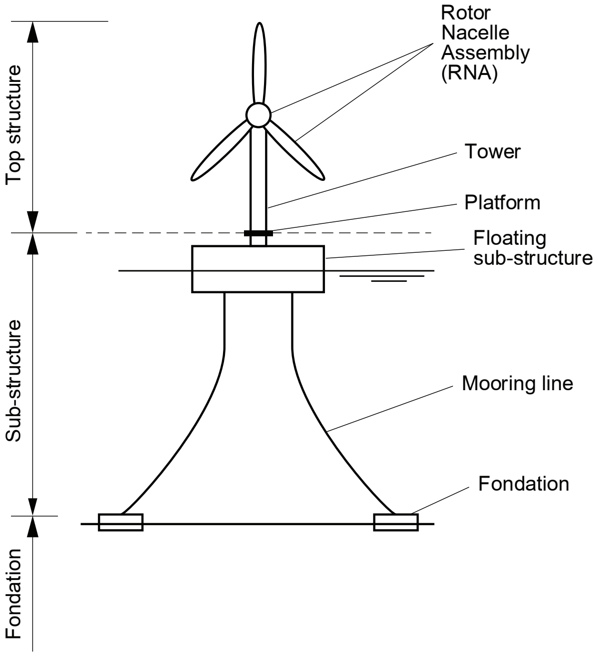

Figure 2 : Axes

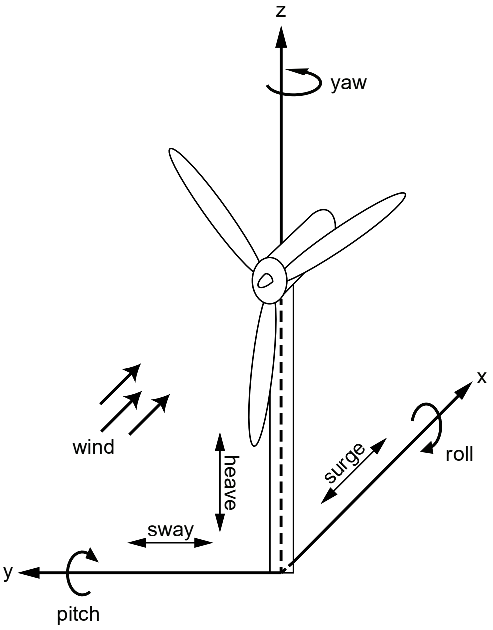

Table 2 : Society documents

Note	Title	Main interest
NR 216	Rules on Materials and Welding for the Classification of Marine Units	General requirements for material
NI 423	Corrosion Protection of Steel Offshore Units and Installations	General guidance on corrosion protection of steel offshore units
NR 426	Construction Survey of Steel Structures of Offshore Units and Installations	Guidance on the construction of steel structures of mobile offshore units and fixed offshore installations
NI 432	Certification of Fiber Ropes for Deepwater Offshore Services	General requirements for fiber ropes
NR 445 **(1)**	Rules for the Classification of Offshore Units	General requirements for offshore units
NR 467 **(2)**	Rules for the Classification of Steel Ships	General requirements for steel ships
NR 493	Rules for the Classification of Mooring Systems for Permanent and Mobile Offshore Units	General requirements for mooring systems
NI 539	Guidance Note on Spectral Fatigue Analysis Methodology for Ships and Offshore Units	General guidance on spectral fatigue
NR 571	Rules for the Classification of Column Stabilized Units	General requirements for column stabilized units
NR 578	Rules for the Classification of Tension Leg Platform	General requirements for tension leg platforms
NR 600	Hull Structure and Arrangement for the Classification of Cargo Ships less than 65m and Non Cargo Ships less than 90 m	General requirements for hull structure
NI 604	Guidance Note on Fatigue of Top Chain of Mooring Lines due to In-plane and Out-of-plane Bendings	General guidance for fatigue of top chain mooring lines
NI 605	Geotechnical and Foundation Design	General guidance on foundations and soil investigations
NI 615	Buckling Assessment of Plated Structures for Offshore Units	Strength criteria for buckling and ultimate strength of structure

(1) Hereafter referred as Offshore Rules
(2) Hereafter referred as Ship Rules

2.2.4 Access platform

The access platform comprises any walkway and platform mounted above the splash zone. The access platform may be integrated to the sub structure and is to be considered as sub-structure in this case. Access platform may be non integrated to the sub structure and is to be considered as top-structure in this case.

2.2.5 Station keeping system

The station keeping system is a system capable to maintain the FOWT in position within specified limits.

2.2.6 Foundation

Foundations are installations at the seabed or in the seabed serving as anchoring of station keeping system and providing the transfer of loads to soil.

Different types of foundations can be encountered:

- anchors: drag anchors, vertically loaded (plate) anchors torpedo anchors
- gravity solutions: dead man anchors
- piled solutions: long piles, short piles and caisson.

2.2.7 Tension Leg Platform (TLP)

Tension leg platforms are floating offshore units connected to the seabed through a tendon legs system (TLS). The TLS ensure the station keeping and restrains the motion of the unit due to wind, waves, current and tidal effects within specified limits.

Tendons are pre-tensioned. Generally very stiff in axial direction, the tendons limit heave, pitch and roll responses to very small amplitudes.

2.2.8 Column stabilized unit

Column stabilized units are units with the main deck connected to underwater hull or footings by columns or caissons. Bracings may be provided between the lower hull or footings, the columns and the deck structure.

2.2.9 Semi-submersible units

Semi-submersible units are column stabilized units for which the deck structure is above the water level and the columns are partially underwater.

A semi-submersible unit is intended for use in the floating mode, unit's stability in working and storm condition being afforded by the column water plane area.

3 Principles of classification and certification

3.1 Classification

3.1.1 Class notation

When classification is requested, the structural type notation **offshore special type unit (FOWT)** is to be granted to the FOWT (see Offshore Rules, Pt A, Ch 1, Sec 2).

3.2 Certification

3.2.1 Certification results in issuance of certificates attesting the compliance of FOWT and/or its components with Rules or standards.

3.2.2 The certification process of a Floating Offshore Wind Turbine consists of review of plans and calculations, surveys, checks and tests intended to demonstrate that standards/national Regulations are met.

3.2.3 Certification in compliance with special national rules

It is reminded that certification of FOWT in compliance with specific national regulations can be delivered by the Society only when it is authorized to do so by the competent National Authority.

3.3 National and International Regulations

3.3.1 FOWT operating in national waters are to comply with the Administration rules in addition to the Society rules.

3.3.2 In case of disagreement between rules, the Administration rules will prevail on the Society rules, except when the later provide a higher safety level. In this case, decision will be taken in agreement between the Society and the Owner, on a case by case basis.

3.3.3 In case of application of statutory requirements, attention is drawn upon the necessary agreement of the flag and/or coastal Authorities.

3.4 Alternative

3.4.1 Risk based approach

The risk based approach may be considered as an alternative or as a complement to Rules to support the adoption of deviations or modifications from the rules requirements. In such a case, the risk assessment documents are to be submitted and agreed by the Society.

4 Documents to be submitted

4.1 Plans and documents to be submitted for review

4.1.1 Documents to be submitted for review include, at least:

- arrangements drawings
- structural drawings of the floating platform and of top-structures, RNA excluded
- operating manual
- details of anchoring system.
- inspection and test plan.

4.1.2 The Society reserves the right to request the submission of the following documents related to the different life cycle phases of the FOWT (see App 1:

- manufacturing documentation
- commissioning manual

4.1.3 Structural plans of sub-structure are to show details of connections of the various parts and, in general, are to specify the materials used, including their manufacturing processes, welding procedures and heat treatments.

4.2 Plans and documents to be submitted for information

4.2.1 Documents submitted for information are not directly concerned by Rules, but providing information useful for the approval of the submitted plans and documents. These documents are not subjected to any assessment by the Society.

4.2.2 When direct calculation analyses are carried out by the Designer according to the rule requirements, they are to be submitted to the Society for information.

4.2.3 Documents to be submitted for information are:

- general description of the offshore wind turbine
- client's specifications
- reports on site specific conditions (soil data, metocean report, etc.)
- basic engineering documents, specifications of the installation
- detailed engineering documents prepared by the concerned Engineering Departments
- documents related with the wind turbine primary components (blades, rotor, bearings, gearbox, brakes, generator, etc.), providing, at least, data on their masses, inertias and stiffness
- description of principles used on the control and safety systems
- calculation notes covering design load cases and other relevant parameters (including unit's installation conditions)
- supporting calculations as necessary to demonstrate the adequacy of the design for all relevant conditions.

4.3 Additional documents

4.3.1 The Society may request any additional document found relevant, during the course of the approval process.

SECTION 2 MATERIAL

1 General

1.1 Application

1.1.1 This Section provides general guidance for materials applied to FOWT.

1.2 Material strength

1.2.1 Reference stress of material R_f

The reference stress of material, R_f, in N/mm², to be considered for strength calculation, is defined by:

$$R_f = \min\left(R_{eG}, \frac{R_m}{1,2}\right)$$

with:

R_{eG} : Minimum specified yield stress of the material, in N/mm²

R_m : Tensile strength of the material, in N/mm².

For steel having a yield stress above 690 N/mm², special consideration will be given by the Society.

Note 1: Refer to NR 216 Materials and Welding.

1.2.2 Equivalent stresses

a) For uniaxial stress condition, the equivalent stress σ_c, in N/mm², at each point, is given by:

$$\sigma_c = \sqrt{\sigma^2 + 3\tau^2}$$

where:

σ : Normal stress

τ : Shear stress

b) For biaxial stress condition, the equivalent stress, at each point, is given by:

- when $\sigma_1 \cdot \sigma_2 > 0$:

$$\sigma_c = \max(|\sigma_1|, |\sigma_2|)$$

- when $\sigma_1 \cdot \sigma_2 < 0$:

$$\sigma_c = \sqrt{\sigma_1^2 + \sigma_2^2 + |\sigma_1 \sigma_2|}$$

Where:

σ_1, σ_2 : Principal stress in the element under study, including the effect of both global and local loads.

2 Temperature

2.1 Design temperature

2.1.1 Design temperature of structural elements is to be taken as follows:

- air temperature for emerged part
- water temperature for immerged part.

2.1.2 Air temperature

Air temperature is to be taken as the mean air temperature of the coldest day (24h) of the year of area of operation.

Where no particular value is specified, the following air temperature is considered:

- 0°C for FOWT not intended to operate in cold area
- −10°C for FOWT intended to operate in cold areas.

2.1.3 Water temperature

Water temperature is to be taken as the mean water temperature of the coldest day (24h) of the year of area of operation.

Where no particular value is specified, water temperature upon 0°C is to be considered.

3 Steel and aluminium material

3.1 General

3.1.1 Material properties are to comply with the Rule Note NR216 Rules on Materials and Welding for Classification of Marine Units, and Offshore Rules, Pt B, Ch 3, Sec 2.

3.1.2 Selection of steel grade

The steel grade for a structural element is to be selected in accordance with Offshore Rules, Pt B, Ch 3, Sec 2, on the basis of:

- the design temperature, as defined in [2.1]
- the structural category, as defined in [3.1.3]
- the reference thickness of the element, as defined in Offshore Rules, Pt B, Ch 3, Sec 2.

3.1.3 Structural categories

Structural elements in welded steel constructions are classed into three categories:

- second category: structural elements of minor importance, the failure of which might induce only localized effects
- first category: main load carrying elements essential to the overall structural integrity of the FOWT
- special category: parts of the first category elements located in way or at the vicinity of critical load transmission areas and of stress concentration locations.

Structural categories are to be indicated on the drawings submitted to the Society for review.

The Society may, where deemed necessary, upgrade any structural element to account for particular considerations such as novel design features or restrictions regarding access for quality control and in-service inspections.

3.1.4 Weld category

A weld is to be classed in the same category as the category of the element on which welding is performed see [3.1.3].

In case of a weld connecting two elements classed in different categories, the weld is to be classed in the category of the higher classed element.

3.2 Corrosion

3.2.1 The scantlings obtained by applying the criteria specified in this Note are net scantlings, except when otherwise specified.

3.2.2 Corrosion protection

Structure of the FOWT is to be effectively protected against corrosion damage using either one or a combination of the following methods:

- cathodic protection
- application of protective coatings
- selection of material.

General requirements are given in Offshore Rules, Pt B, Ch 3, Sec 5 and in NI 423.

3.2.3 Protection against galvanic corrosion is to be provided when metallic and composite material, such as carbon fibre, are used together.

3.2.4 Corrosion addition

The values of the corrosion additions specified hereafter are to be applied in relation to the relevant protective coatings given in [3.2.2].

The Designer may define greater values of corrosion additions.

a) Steel other than stainless steel

In general, the corrosion addition to be considered for plating forming the boundary between two compartments of different types is equal to:

- for plating with a gross thickness greater than 10 mm, the sum of the values specified in for one side exposure to each compartment
- for plating with a gross thickness less than or equal to 10 mm, the smallest of the following values:
    - 20% of the gross thickness of the plating
    - sum of the values specified in Tab 1 for one side exposure to each compartment.

For an internal member within a given compartment, or for plating forming the boundary between two compartments of the same type, the corrosion addition to be considered is twice the value specified in for one side exposure to that compartment.

When, according to Tab 1, a structural element is affected by more than one value of corrosion additions, the scantling criteria are generally to be applied considering the maximum value of corrosion addition applicable.

b) Stainless steel

For structural members made of stainless steel, the corrosion addition t_c is to be taken equal to 0.

c) Non alloyed steel clad with stainless steel

For plates made of non-alloyed steel clad with stainless steel, the corrosion addition t_c is to be taken equal to 0 only for the plate side clad with stainless steel.

d) Aluminium alloys

For structural members made of aluminium alloys, the corrosion addition t_c is to be taken equal to 0.

4 Concrete

4.1 General

4.1.1 For concrete material of the FOWT, reference is to be made to the applicable requirements of standards for the design of concrete structures, such as:

- Eurocode 2 - Design of concrete structures
- EN 206 - Concrete - Specification, performance, production and conformity
- ISO 19903 - Fixed concrete offshore structures.

Table 1 : Corrosion additions t_c, in mm, for each exposed side

Compartment type		General **(1)**	Special cases
Ballast tank		1,00	1,25 in upper zone **(2)**
Fuel oil tank	Plating of horizontal surfaces	0,75	1,00 in upper zone **(2)**
	Plating of non-horizontal surfaces	0,50	1,00 in upper zone **(2)**
	Ordinary stiffeners and primary supporting members	0,75	1,00 in upper zone **(2)**
Tanks for fresh water		0,5	
Moonpool		1,25	
Accommodation space		0,00	
Compartments other than those mentioned above Outside sea and air		0,50	

(1) General: corrosion additions t_c are applicable to all members of the considered item with possible exceptions given for upper and lower zones.

(2) Upper zone: area within 1,5 m below the top of the tank. This is to be applied only to tanks with weather deck as the tank top.

SECTION 3 DESIGN CONDITIONS AND LOADS

1 General

1.1 Principles

1.1.1 Application

This Section provides guidance for design loads applied for structural assessment of FOWT.

1.1.2 Direct calculations and model tests

Direct calculations are to be carried out as required in this Note. Direct calculations may be calibrated based on model tests. In such a case, testing procedures and method used for the extrapolation of model tests to full scale data are to be at the satisfaction of the Society.

1.2 Operating Manual

1.2.1 The Operating Manual is a document which includes instructions regarding the safe operation of the FOWT and of the systems and equipment fitted on the unit, is to be placed at the base of maintenance of the unit and made available to all concerned. A copy of the Operating Manual is to be retained ashore by the Owners of the FOWT or their representatives.

Note 1: Base of maintenance may be located offshore or onshore.

The Operating Manual is to incorporate a dedicated section containing information relating to:

- all design conditions on which the design of the FOWT is based
- all permissible limits and operational limits applied for the design
- all allowable local loadings for the hull, decks and foundations.

1.2.2 The Operating Manual of the FOWT is to be submitted for review to the Society.

2 Design conditions

2.1 General

2.1.1 Design conditions on the basis of which the structural checks are performed cover all stages of FOWT's life entering under the scope of the Society.

2.1.2 A design condition is defined by a combination of the following main conditions:

- Operating conditions
- System conditions
- Environmental conditions.

2.2 Operating conditions

2.2.1 Production conditions

Production conditions corresponds to the situation where the FOWT is running and is connected to the electrical network. Production of electricity is performed.

2.2.2 Parked conditions

Parked conditions correspond to the situation where the RNA is in a standstill or idling condition. Turbine is stopped.

2.2.3 Transit, Installation and Maintenance conditions

Transit, Installation and Maintenance conditions correspond to the conditions assumed for the transportation, assembly, maintenance and repair on site of the FOWT.

2.3 System conditions

2.3.1 Intact conditions

Intact conditions of the FOWT correspond to the normal state of the FOWT.

Intact conditions may consider minor fault which are expected to occur frequently during the FOWT life time.

2.3.2 Abnormal conditions

Abnormal conditions of the FOWT corresponds to a design condition with severe fault that result in activation of protection system.

a) For the structural part, abnormal conditions include:
   - Structure damage
   - Flooding
   - Station keeping damage
   - Fire and explosion.

b) For the electrical part, abnormal conditions include:
   - Loss of electrical network
   - Internal electrical fault
   - Control system fault
   - External electrical fault
   - Protection system fault.

2.4 Environmental conditions

2.4.1 Environmental conditions are external conditions due to wind, sea and ice. More details on external conditions are given in App 3.

2.4.2 Wind conditions

Wind conditions correspond to the description of wind on the FOWT site. Wind conditions are grouped into two main categories:

a) Normal wind conditions

Normal wind conditions occur frequently during the life time of the FOWT and include:

- normal wind
- operating gust
- wind turbulence
- direction change
- coherent gust with direction change
- wind shear.

Note 1: Normal wind conditions correspond to the wind conditions acceptable to perform electricity production. Range of wind speed is given by the turbine manufacturer.

b) Extreme wind conditions

Extrem wind conditions occur rarely during the life time of the FOWT. Return period of 50 years is generally to be considered.

Note 2: During extreme wind conditions, no electricity is produced, the turbine has to be stopped.

Additional guidelines are given in App 3.

2.4.3 Marine conditions

Marine conditions correspond to the description of the sea state on the FOWT site. It includes:

a) Wave conditions

Wave conditions correspond to the description of wave of the intended site of the FOWT. Sea state is given in term of wave height:

- normal wave height (NWH)

  The normal wave height correspond to the wave height conditioned to the normal wind.
- severe wave height (SWH)

  The severe wave height corresponds to the wave height associated to normal wind condition for which the combination wind and wave has a return period of 50 years.
- extreme wave height (EWH)

  The extreme wave height correspond to the wave height associated to a return period of 50 years.

b) Current conditions

c) Tidal conditions

d) Marine growth conditions.

Additional guidelines are given in App 3.

2.4.4 Ice conditions

Ice conditions correspond to the description of the ice state on the FOWT site.

Additional guidelines are given in App 3.

3 Design loads

3.1 General

3.1.1 The design of FOWT structures is considering the following categories of loads:

- fixed
- operational
- external (environmental and electrical)
- accidental.

Note 1: Categories of loads are also defined in Offshore Rules Pt B, Ch 2, Sec 3.

3.2 Fixed loads

3.2.1 Fixed load or lightweight is the weight of the complete FOWT with all permanently attached machineries, equipment and other items of outfit.

3.2.2 Fixed loads include, for example:

- weight of the structure (rotor, nacelle, mast, floater,...)
- weight of permanent ballast to their normal working level
- weight of permanent liquids (lubricating oil in generator).

3.2.3 Fixed loads exclude weight of liquids or other fluids contained in supply, reserve or storage tank.

3.2.4 Load distribution

For the purpose of overall structural calculations, a complete description of load distribution is to be provided.

3.3 Operational loads

3.3.1 Operational loads are loads associated with the operation of the FOWT, corresponding to the specified operating condition. They include:

- hydrostatic loads (buoyancy)
- loads resulting from liquids in tanks
- variable ballast loads
- loads resulting from lifting appliances in operation
- actuation loads
- vessel impact loads due to normal operation
- variable loads of consumable supplies weights
- dynamic loads induced by equipment in operation.

3.3.2 Hydrostatic loads

The maximum and minimum draughts in each loading condition are to be considered for calculation of hydrostatic loads on outer shell. If the shell forms tank boundary, the maximum or minimum differential pressure between internal and external pressure is to be considered as well.

Note 1: Mooring tendon and power cable loads can have an important effect on hydrostatic loads.

3.3.3 Vessel impact loads

Vessel impact loads are loads resulting from the normal service of the vessel (e.g. transfer of personnel).

Note 1: Vessel impact loads due to accidental situation are to be considered as accidental loads, see [3.5].

Vessel impact loads are to be applied in combination with the most severe environmental loads corresponding to the operation of the vessel.

Maximum environmental conditions (maximum significant wave height) and areas allowed close to the FOWT for vessel operation are to be stated in the operation manual.

Note 2: Considering the vessel operates on the FOWT because of maintenance, the FOWT is considered as in parked condition, the turbine is stopped.

3.4 External loads

3.4.1 External loads are mainly constituted by environmental loads and electrical loads.

For external conditions, general guidances are given in App 3.

3.4.2 Environment loads

Environmental loads are loads resulting from the action of the environment on the FOWT, corresponding to the specified environmental condition. They include:

- wind loads
- wave, current, tidal and marine growth loads
- ice loads
- inertia loads.

3.4.3 Wind loads

Wind loads are loads due to the wind effect on the FOWT corresponding to the specified wind condition.

Wind loads are to be defined in terms of wind conditions for the specific site.

For FOWT, wind loads may be divided into two components:

- wind loads acting on the tower and the substructure
- wind loads acting on the rotor.

a) Wind loads on the substructure and the tower

Wind loads acting on the substructure and the tower can be considered as steady loads and determined by the following formula:

$$F_w = 0,5\,\rho C_s S_w V_w^2$$

where:

ρ : Air specific mass, in kg/m^3

Generally, $\rho = 1,222$ kg/m^3

S_w : Projected area of the structural element on a plane normal to the direction of the force, in m^2

V_w : Mean wind speed at the considered elevation, in m/s

C_s : Shape coefficient, values given in Tab 1 may be used in absence of data.

b) Wind loads on the rotor

For determination of the overturning moment (stability analysis), the wind drag force, F_D in N, acting on the rotor may be calculated by the following formula:

$$F_D = 0,5\rho C_D S V_{hub}^2$$

where:

ρ : Air density, in kg/m^3

C_D : Drag coefficient

S : Swept area of the blades, in m^2

V_{hub} : Mean wind speed at hub height, in m/s.

Additional guidelines are given in App 3.

Note 1: Further guidance on wind loads force is given in IMO MODU Code.

Table 1 : Shape coefficient C_s

Shape	C_s
Spherical	0,4
Cylindrical	0,5
Rectangular	1,5
Large flat surface	1,0
Wires	1,2
Exposed beams and girders under deck	1,3
Small parts	1,4
Isolated shapes (crane, beam, etc...)	1,5
Clustered deckhouses or similar structures	1,1

3.4.4 Wave loads

Wave loads are to be defined in accordance with the requirements of Pt B, Ch 2, Sec 3, [3.3] of the Offshore Rules.

Appropriate hydrodynamic analysis and model tests are mandatory for the assessment of wave loads.

Additional guidelines are given in App 2 and App 3.

Note 1: For TLP, special attention is to be paid on ringing and springing effects.

Note 2: For column stabilized unit, special attention is to be paid on squeeze and pry effect, where applicable.

Squeeze effect occur when lateral loads on columns due to waves are maximum inward toward the center of the floating platform, squeezing the columns toward each other. Prying is the opposite effect, when lateral load is outward away from the platform center.

Squeeze and pry load effects may be determinant for the connection between columns and pontoons and for the interconnection between the hull and decks.

3.4.5 Current loads

Current loads are to be calculated in compliance with the requirements given in Pt B, Ch 2, Sec 2, [4] of the Offshore Rules.

Special attention is to be paid on the combination of waves and currents speeds when Morison calculation are performed.

Additional guidelines are given in App 3.

Note 1: For TLP, special attention is to be paid on Vortex Induced Vibration (VIV) and Vortex Induced Motion (VIM) on tendon and slender members.

3.4.6 Inertia loads

Inertia loads are loads resulting from dynamic loads induced by FOWT's motions, vibration and rotation.

Note 1: For FOWT, inertia loads can contribute to increase dynamic response from aerodynamic and hydrodynamic calculation. Attention is to be paid on gyroscopic loads.

3.4.7 Ice loads

When the FOWT is exposed to ice environment, ice loads are to be considered:

- loads from ice impact on floating sub-structure
- overloads from ice and snow accumulation.

Note 1: Ice management system may be used to reduce loading due to ice action.

3.4.8 Tsunami

Tsunami loads are loads induced by elevation of sea water surface level and current.

The sea water elevation due to tsunami depends on water depth. In deep waters, tsunami elevation is small and may be non detectable. When the tsunami arrives in shallow water, the tsunami elevation is amplified.

Note 1: For FOWT equipped with a tsunami warning system which shut down the turbine, tsunami loads can be ignored for the "In operation" conditions.

3.4.9 Earthquakes loads

Earthquake loads are loads resulting from seismic activity and are to be considered for FOWT located in region considered as seismically active.

General guidance on seismicity is given in ISO 19901-2 Seismic design procedures and criteria.

Note 1: For TLP, design can be significantly impacted as the sensibility to earthquake is related to the restrained motions.

3.5 Accidental loads

3.5.1 Accidental loads are loads resulting from abnormal condition and include loads resulting from:

- hydrostatic pressure in damaged condition
- accidental flooding
- breaking of mooring lines or tendons, as applicable
- unintended ballast
- collision with supply vessels or other relevant collision scenarios
- dropped objects taking into account all equipment susceptible to drop on the hull or decks during transit and operations
- fire and explosion
- electrical fault.

  If relevant, active control systems in the floating support structure, such as active ballast, faults of such systems are to be considered.

4 Load cases

4.1 General

4.1.1 Load cases consist in combination of design loads applicable for specified design condition.

Load cases are defined in order to maximize or minimize a loading effect relevant for the FOWT.

4.1.2 A specific table of design load cases applicable to the FOWT is to be defined.

Special care is to be drawn, in view to avoid any ambiguity regarding the choice of applicable safety factors.

4.1.3 Combination of environmental loads

For the purpose of environmental loads combination, environmental elements are to be assumed to act simultaneously in the same direction, unless combinations of environmental elements with different directions can be more severe and liable to occur.

Note 1: For FOWT, wind, wave and current misalignment can lead to higher loading, for instance mooring.

Considering combination of wind loads and sea loads, special care is to be paid on aerodynamic interaction between the airflow and the FOWT. Large motions of the floater (translation and rotation) may impact the loading of the RNA and tower (aero elastic effects, blade vortex interaction, dynamic stall,...). The stream tube based on induction models may be deficient.

4.2 Design Load Cases

4.2.1 As a guidance, the FOWT is to be designed for at least the load cases defined in [4.2.2] to [4.2.5]. Other design load cases that can be more critical are also to be investigated.

4.2.2 Load cases 1 "Normal (N)"

These load cases refer to the most unfavourable combination of the fixed, operational and external loads, including loads associated to:

a) production conditions with normal wind conditions and severe wave height

b) parked conditions with extreme wind conditions and extreme wave height.

When wind extreme turbulence, gust, wind direction change or specific wave height may be critical, resulting load cases are to be investigated.

4.2.3 Load cases 2 “Accidental (A)”

These load cases refer to the combination of the fixed, operational and external loads with accidental loads.

When relevant, the fault of sea state limit protection system is to be considered.

4.2.4 Load cases 3 “Transport, IMR (T)”

These load cases refer to the combination of the specified loads for the FOWT transportation, installation, maintenance and repair.

4.2.5 Load case 4 “Fatigue (F)”

For fatigue evaluation, a sufficient number of load cases is to be considered to accurately model loads acting on the FOWT during its whole life, giving due consideration to:

- the various operating conditions of the FOWT
- the direction and the intensity of environmental actions, as resulting from the long term distributions of the relevant environmental parameters with possible limitations corresponding to each of these conditions.

SECTION 4 STABILITY

1 General

1.1 Application

1.1.1 This Section provides general guidance relating to the stability of the FOWT.

1.1.2 Stability and watertightness of FOWT are to comply with applicable requirements of Offshore Rules, Part B, Chapter 1, or subject to a preliminary agreement, in accordance with other particular specifications based on the same principles or relevant National or International Regulations, assuming the environmental conditions specified in Sec 3.

1.2 Statutory requirements

1.2.1 Attention is drawn to special legal provisions enacted by National Authorities which FOWT may have to comply with according to their structural type, size, operational site and intended service, as well as other particulars and details.

1.2.2 Compliance with statutory requirements is not included in this Note but, in case of conflict between the Rules and these requirements, the later ones are to take precedence over the requirements of this note.

Note 1: The Society may take into consideration particulars which may be called for or authorised by the competent National Authorities.

1.3 Operating procedures

1.3.1 Adequate instructions and information related to the stability, watertight integrity and weathertight integrity of the FOWT are to be provided by the Owner and included in the Operating Manual.

Note 1: Procedures and operating instructions do not fall within the scope of the classification and need not to be approved by the Society.

1.4 Stability calculations

1.4.1 Cases for stability calculations

Stability calculations are to be carried out and submitted to the Society for review for the following cases:

a) lightweight condition

b) transit departure and arrival conditions, if relevant, anchors to be onboard and with the maximum related deck loads

c) towing condition, if relevant

d) normal working condition at maximum draught with the maximum deck loads and equipment in the most unfavorable positions

e) inspection conditions consistent with the operational procedure

f) severe storm condition assuming the same weight distribution as in item a), except for the necessary ballast adjustments to bring the FOWT to the survival draught and for the possible dumping of variable deck load if such is specified in the operating procedures

g) severe storm condition assuming the same weight distribution as in item b) with the necessary ballast adjustments to place the unit in the survival draught configuration, when applicable. In this condition:
  - equipment liable to be disconnected is assumed disconnected
  - equipment liable to be disconnected and stored on deck is assumed disconnected and secured on deck
  - equipment having a rest position, such as crane booms, is assumed in rest position.

The maximum amount of loads is assumed to be stored on deck. Account may be taken of dumping of variable deck load if specified.

1.4.2 Ice and snow

For FOWT liable to operate in areas of snow and glazed frost, verification of the stability, intact and damage, is to be performed taking into account the possible overloads due to ice and snow accumulation.

In order to perform the stability calculation, the following amount of ice may be used:

- 140 kg/m^2 for horizontal exposed areas
- 70 kg/m^2 for lateral or oblique exposed areas.

Different amount of ice corresponding to local regulations or areas where units are operating may be used instead of the above values.

2 Intact stability

2.1 Application

2.1.1 Stability is to be assessed for intact conditions

2.2 Criteria

2.2.1 The intact stability criteria for each operating condition (production, parked, transit) are those stated in Offshore Rules, Pt B, Ch 1, Sec 3.

Note 1: Attention is drawn to requirements from local authorities, see [1.2].

2.3 Stability analysis

2.3.1 The intact stability analysis is to consider:

- site specific environmental conditions (wind, wave, green water effects, if applicable)
- freezing of ballast water, if applicable
- quasi-static effects of RNA operating conditions (overturning moment)

3 Damaged stability

3.1 Application

3.1.1 Damage stability is to be considered according to Offshore Rules, Part B, except for the cases of explicit exclusion given in the terms of the contract, and approved by National Authorities.

3.2 Criteria

3.2.1 The damage stability criteria for each operating condition (production, parked, transit) are those stated in Offshore Rules, Pt B, Ch 1, Sec 3.

SECTION 5 STRUCTURE DESIGN

1 General

1.1 Application

1.1.1 This Section provides general guidance relating to the structural design of the FOWT.

Note 1: Guidance on structural analysis is given in Sec 6.

1.1.2 Only the floating platform of the sub-structure is covered by this section, the station keeping system is covered by the relevant sections, (see Sec 8 and Sec 9).

1.1.3 Design life

In general, FOWT are designed to have service life not less than 20 years.

1.2 Rules and standards

1.2.1 Society Rules

The concerned Society rules are as follow:

- Ship Rules, Part B and Part C
- Offshore Rules, Part B and Part D
- NR571 Rules for the Classification of Column Stabilized Units
- NR578 Rules for the Classification of Tension Leg Platform
- NR426 Construction Survey of Steel Structures of Offshore Units and Installations
- NI 615 Buckling Assessment of Plated Structures for Offshore Units.

1.2.2 Other standards

The recognized Codes and Standards are as follow:

- AISC Steel Construction Manual
- API RP 2A-WSD
  API RP 2A-LRFD
- ISO 1993-1 Design of steel structure.

2 General structural principles

2.1 General

2.1.1 When relevant, requirements from Ship Rules, Pt B, Ch 4, Sec 3 to Pt B, Ch 4, Sec 7 are applicable.

2.1.2 Mean of access

The means of access are to allow inspection of the critical structure connections.

The number of inaccessible areas is to be limited and clearly identified on the structure drawings. The Society reserves the right to require additional corrosion allowances for these areas. Special attention is to be paid to fatigue strength.

Web frame numbers are to be attached to structure or walkway inside of tanks to the satisfaction of the attending Surveyor.

Equipment on deck are to be arranged to allow inspections of the deck plating and to avoid permanent concentration of dust and remaining water.

2.1.3 Deck clearance / Air gap

Unless the deck structures are designed to withstand wave impact loading, the underside of deck is to be clear of passing wave crests under all design conditions.

When wave impacts are permitted to occur on the underside of topside deck, it is to be demonstrated that the safety of personnel is not significantly impaired.

The following clearances are to be maintained between the underside of the topside deck and the wave crest:

- positive air gap for extreme conditions
- 1,5 m for all others design conditions.

Deck clearances are to be checked at various points on the underside of the topside deck.

Deck clearances are normally determined by appropriate model tests. Detailed hydrodynamic analysis are accepted, provided that the following items are taken into account:

- relative motions between the FOWT and waves
- generally, the nonlinearity of wave profile
- maximum and minimum draughts
- various environmental headings.

2.2 Structural continuity

2.2.1 Attention is to be paid to the structural continuity:

- in way of changes in the framing system
- at the connections of primary or ordinary stiffeners
- in way of deck equipment connections.

a) The framing system of the hull is to consider the global stress flow. In principle, several framing types are adopted for triangular hulls. Rectangular hulls are usually longitudinally framed

Note 1: For column stabilized units, internal structure of columns in way of bracing is to be capable to sustain the axial strength of the bracing.

b) Where stress concentrations may occur in way of structural discontinuities, adequate compensation and reinforcements are to be provided.

Primary supporting members are to be arranged in such a way that they ensure adequate continuity of strength.

Abrupt changes in height or in cross-section are to be avoided

c) Openings are to be avoided, as far as practicable, in way of highly stressed areas.

Where necessary, the shape of openings is to be specially designed to reduce the stress concentration factors. Particular attention is to be paid to the passage of secondary stiffeners through web plating in the vicinity of heavy loads.

Openings are to be generally well rounded with smooth edges.

2.2.2 Sniped ends

In principle, sniped ends of primary and secondary stiffeners are to be less than 30 degrees.

2.2.3 Plating

A local increase in plating thickness is generally to be achieved through insert plates.

Insert plates are to be made of materials of a quality at least equal to that of the plates on which they are welded.

Plating under heavy concentrated loads may be reinforced with doublers (only compression loads allowed) and/or stiffeners where necessary. Doublers in way of equipment are to be limited in size and avoided in areas of the deck with high stress.

Doublers are to be fitted with slot welds, according to the Ship Rules, Pt B, Ch 11, Sec 1, when their width, in mm, is greater than:

- 20 times their thickness, for thicknesses ≤ 15 mm
- 25 times their thickness, for thicknesses > 15 mm.

2.2.4 Ordinary stiffeners

The strength principles requirements for the ordinary stiffeners are those given in Ship Rules, Pt B, Ch 4, Sec 3, [3].

2.2.5 Primary supporting members

The strength principles requirements for the primary supporting members are those given in Ship Rules, Pt B, Ch 4, Sec 3, [4].

2.2.6 Reinforcements in way of supporting structures for hull attachments

Generally, the supports for attachments and appurtenances are to be fitted in way of longitudinal and transversal bulkheads or in way of deck beams. Other supports are to be fitted in way of large primary supporting members.

The main structure may be locally reinforced by means of insert plates.

Cut outs in local structure in way of hull attachments are to be closed by full collar plates.

Particular attention is to be paid to buckling below supports.

2.2.7 Welding

The design of weld connections of all structural members, including the tubular connections, is to comply with requirements of NR426.

For size of the fillet welds, reference may be made to AWSD D1.1 Structural welding Code - Steel, in its latest edition.

2.3 Small hatches

2.3.1 Small hatches requirements are those given in Ship Rules, Pt B, Ch 8, Sec 8.

3 Structural assessment

3.1 General

3.1.1 The purpose of the resistance check is to demonstrate that the FOWT is capable to withstand loads (defined in Sec 3) and/or operate under the following limit states:

- ultimate limit states (ULS), corresponding to the maximum load carrying resistance (see [4])
- fatigue limit states (FLS), relating to the possibility of fatigue failure due to cyclic loads (see [5])
- serviceability limit states (SLS), corresponding to the criteria applicable for normal use of the FOWT or durability see [6].

3.1.2 The design of the FOWT structure is to be performed based on recognized methods, considering Rules and standards as stated in [1.2].

3.1.3 Design format

The allowable stress (WSD) is used to formulate the strength criteria of this Note.

However, FOWT design based on Load and Resistance Factor Design (LRFD) format may be accepted. In that case, design values are to take into account the uncertainties and variabilities by appropriate partial safety factors, γ_i, as given in Tab 1 for loads and Tab 2 for materials and resistance. For the fatigue evaluation, the partial safety factors are to be taken as 1,0.

Note 1: Attention is drawn that partial load factors may not be applicable to loads which are not independent. In such a case, only a global factor can be used.

Table 1 : LRFD - Partial safety factors for loads

Kind of loads	Partial safety factors		
	Load case 1 (N)	Load case 2 (A)	Load case 3 (T)
unfavorable **(1)**	1,35	1,1	1,5
favorable	0,9	0,9	0,9
Partial safety factors are to be stated in the design documentation. **(1)** For fixed loads and consumable supplies weights, partial safety factor is to be taken equal to 1,0 for all design condition.			

Table 2 : LRFD - Material and resistance partial safety factors

	γ_m	γ_R	
		yielding	buckling
Ordinary stiffeners	1,02	1,02	1,10
Plating	1,02	1,20	1,10
Primary supporting members **(1)**	1,02	1,02	1,15 **(2)**
Bolted connections, fillet, partial penetration welds	1,02	1,30	-

Partial safety factors are to be stated in the design documentation.

(1) For members analyzed through three dimensional beam model or coarse mesh finite model, $\gamma_R = 1,20$

For members analyzed through three dimensional fine or very fine mesh finite element model, $\gamma_R = 1,05$

(2) For torsional and local buckling, $\gamma_R = 1,05$

4 Ultimate limit state (ULS)

4.1 General

4.1.1 The ultimate limit state corresponds to the maximum load-bearing capacity.

It includes:

- ultimate strength
- buckling.

4.1.2 The strength and stability of the structure are to be checked against ultimate strength and buckling criteria stated respectively in [4.2] and [4.3].

For structural elements not covered by the Society Rules, design is to be performed in accordance with recognized methods. In that case, criteria stated in such methods are to be considered with deviation specified in this Note.

4.1.3 Strength analysis

Strength analysis is to be carried out in order to check the structural stress in relation to yielding and buckling stress. Guidance on strength analysis is given in Sec 6.

The strength of structural elements is to be ascertained for the effect of stresses resulting from:

a) For all structural elements:
  - axial loads
  - bending
  - shear
  - buckling.

b) For tubular elements:
  - combined axial compression and bending
  - combined axial compression and local pressure
  - combined axial tension and bending
  - combined axial tension and local pressure
  - shear
  - hydrostatic pressure.

Note 1: Members may be considered as tubular when they satisfy the following criteria:

$D / t < 120$

with

D : Structure diameter, in m

t : Thickness, in m.

Note 2: Guidance may be found in standard API - RP 2A. Both tubular members and joints are to be considered.

Strength analysis is to be performed for at least the design load cases specified in Sec 3.

4.2 Ultimate strength criteria

4.2.1 Ultimate strength check

The calculated stresses σ_c are not to exceed the allowable stress, σ_{ALL}, for the loading condition considered, according to the following formula:

$$\sigma_c \leq \sigma_{ALL}$$

where:

$$\sigma_{ALL} = \frac{R_f}{SF}$$

with:

R_f : Reference stress of material, in N/mm², as defined in Sec 2, [1.2.1]

SF : Safety factor, as given in Tab 3.

Table 3 : Safety factor SF, for yielding

	Load case 1 (N)	Load case 2 (A)	Load case 3 (T)
SF **(1)**	1,35	1,10	1,50

Safety factors SF, are to be stated in the design documentation

(1) On a case by case basis, when load assessment may be considered with high level of confidence, safety factor values may be reduced by 15% for the load cases 1 (N) and 2 (A).

4.3 Buckling

4.3.1 General

The buckling strength of the structural element is to be ascertained considering the most unfavorable combinations of loads likely to occur, with respect to possible modes of failure.

4.3.2 Stiffened panels

For stiffened panels, buckling check is to be performed according to guidance note NI 615.

The buckling of tubular members is to be checked according to recognized codes or standards.

Note 1: The allowable utilisation factor η_{ALL} is given in [4.3.4].

4.3.3 Unstiffened and ring-stiffened cylindrical shell

For unstiffened or ring-stiffened cylindrical shells, both local buckling and overall buckling modes are to be considered for buckling strength assessment.

4.3.4 Buckling check

A structural element is considered to have an acceptable buckling capacity if its buckling utilisation factor η satisfies the following criterion:

$$\eta \leq \eta_{ALL}$$

with:

$$\eta_{ALL} = \frac{1}{SF}$$

With SF given in Tab 4.

The buckling utilisation factor η of the structural member is defined as the highest value of the ratio between the applied loads and the corresponding ultimate capacity or buckling ultimate capacity or buckling strength for the different buckling modes.

Table 4 : Safety factor SF, for buckling

	Load case 1 (N)	Load case 2 (A)	Load case 3 (T)
SF **(1)**	1,50	1,20	1,67

Safety factors SF, are to be stated in the design documentation

(1) On a case by case basis, when load assessment may be considered with high level of confidence, safety factor values may be reduced by 15% for the load cases 1 (N) and 2 (A).

5 Fatigue limit state (FLS)

5.1 General

5.1.1 The fatigue limit states refer to the damage due to the repetition of actions, typically from waves, wind, current and tidal.

Note 1: Fatigue due to transit may be considered especially for long transit duration.

5.1.2 Structural elements for which fatigue is a probable mode of failure are to be adequately designed to resist the effects of cumulative damage caused by repeated application of fluctuating stresses.

5.1.3 Fatigue evaluations are to be carried out according to recognized methods.

Note 1: For TLP platform, fatigue assessment of hull may be carried out according to API RP 2T.

5.1.4 Fatigue life

The design is to ensure a design fatigue life at least equal to the design life of the FOWT mentioned in [1.1.3].

A further increase in the design life is to be considered for elements in non inspectable areas or areas where repair within the expected life time is not possible or practicable, see Tab 5.

5.1.5 Stress concentration factor (SCF)

Proposed SCF's are to be duly documented to the satisfaction of the Society (see also Sec 6, [4.3])

5.1.6 Local effects, resulting from residual stresses and from weld surface defects, are to be accounted for through joint classification.

5.2 Fatigue check

5.2.1 The fatigue damage ratio is to be not greater than fatigue factor, FF, given in Tab 5.

Table 5 : Fatigue factors, FF

Consequence of failure	Degree of accessibility for inspection, maintenance and repair		
	Not accessible **(2)**	Underwater inspection **(3)**	Dry inspection
Critical **(1)**	0,1	0,25	0,5
Non-critical	0,2	0,5	1,0

(1) Critical damage as per risk analysis including loss of life, uncontrolled pollution, collision, other major damage to the FOWT and major production losses.
When risk analysis report categorizing structural elements as critical or non-critical is not available, all structural elements are considered as critical.

(2) Includes areas that can be inspected in dry or underwater conditions but require heavy works for repair.

(3) Includes areas that can be inspected in dry conditions but with extensive preparation and heavy impact on operation.

6 Serviceability limit state (SLS)

6.1 General

6.1.1 The serviceability limit state concerns the normal use of the FOWT. It includes:

- deformations
- vibration amplitudes and accelerations
- crack widths
- water tightness
- offset with relationship to damaging subsea cabling or interfering with neighbouring facilities
- motions and inclination angles that exceed the limitations of equipment.

6.1.2 Attention is to be paid on the excess of limiting values which can prevent from safe operation, such as:

- excessive motions of the FOWT floater towards neighbouring structure
- deformations of the tower.

Excessive values are to be avoided.

6.2 Criteria

6.2.1 Serviceability criteria are defined based on tolerance for the good operation of the wind turbine as described by the turbine manufacturer. If not specified, criteria specified hereafter are to be used.

6.2.2 Maximum vertical deflection δ_{max}

The maximum vertical deflection, δ_{max}, is to satisfy the following criteria:

$$\delta_{max} \leq L/300$$

where:

L : Span of the beam, in m.

SECTION 6 STRUCTURAL ANALYSIS

1 General

1.1 Application

1.1.1 This Section provides general guidance relating to the structural analysis of the FOWT.

2 General procedure

2.1 General

2.1.1 Structure analysis is performed to determine data for assessment of the FOWT structure. Limit states (see Sec 5, [3.1.1]) are analyzed considering the following analysis:

- Strength analysis, see [3]
- Fatigue analysis, see [4].

2.2 Method

2.2.1 The design of the FOWT structure is to be performed based on recognized methods, considering Rules and standards as stated in Sec 5, [1.2].

Details of the design methodology are to be reported by the applicant.

3 Strength analysis

3.1 General

3.1.1 The strength analysis purpose is to determine stresses into the structure in order to check strength criteria given in Sec 5.

A global strength analysis is to be performed considering the entire FOWT structure.

For details, such as connections or discontinuities, local strength analysis (considering the area of interest) may be performed in order to obtain an accurate representation of stresses (top-down analysis).

3.1.2 Process

The general procedure of strength analysis follows generally the following different steps:

- Loads and loads effects calculations, see [3.2]
- Extrema estimation, see [3.3]
- Stress calculations, see [3.4].

3.2 Loads and loads effects calculations

3.2.1 General

Based on load cases defined in Sec 3, [4], loads and their effects on the FOWT structure are to be determined.

Due to non linearity of the phenomena, calculations are to be performed by direct simulations in time domain.

Quasi-static analyses may be accepted, on a case by case basis, by adopting relevant dynamic amplification factors, which are to be approved by the Society.

3.2.2 Time domain analysis

Time domain analysis of 3 hours are generally to be performed to determine the load responses of the FOWT on the given environmental conditions for structural assessment purpose.

The time domain analysis may consider dynamic models as described in [3.2.3].

3.2.3 Dynamic model

Dynamic models are to take into account all main components of the structure, in view of capturing:

- the global structural behavior of both the top-structure and the sub-structure (including non linear behavior)
- any coupling effects caused by the simultaneous application of external loads (aerodynamic, hydrodynamic, electric, etc).

If these effects are not considered as being relevant for the structure, the technical evidences are to be provided, either by the performance of tests or calculations.

The choice of dynamic models for the implementation of the design procedure remains of the entire responsibility of the applicant.

3.2.4 The dynamic model may be decomposed into the followings:

a) hydrodynamic model:
   determination of waves forces, as defined in [3.2.5]

b) mooring model:
   determination of mooring response, as defined in [3.2.6]

c) structural model:
   determination of internal loads (forces and moments), as defined in [3.2.7].

3.2.5 Hydrodynamic model

The hydrodynamic model provides hydrodynamic loads. It considers diffraction/radiation loads and Morison loads:

- for large structures, diffraction and radiation model is used
- for slender structures, Morison model is used.

Note 1: For columns, only Morison damping term may be considered in Morison elements.

Note 2: Hydrodynamic considerations are given in App 2.

3.2.6 Mooring model

The mooring model provides mooring tensions (vertical and horizontal) at mooring points for each time step (see Sec 8).

3.2.7 Structural model

Structural model is a Finite Element Model (FEM).

For example, the FEM may consist in a model where each part of the structure is modelled with beam elements in order to determine internal forces and moments in beams due to hydrodynamic responses from hydrodynamic model (see [3.2.5]).

An integration model is generally required to transfer the hydrodynamic responses to the structural model. The integration mesh consists in soft panel (with no mass) where the pressure is calculated. All the nodes of these panels are attached to the beams with rigid elements.

Note 1: Integration model is not limited to the draft of the FOWT as dynamic pressures are to be calculated on the whole wetted surface.

Concentrated masses are used to adjust whole mass and inertia of the model.

Note 2: Characteristics of each beam (inertia, area) may be calculated with different methods, such as analytical method for simple sections (tower, cylinder braces), dedicated software or FEA (Finite Element Analysis) for connections.

Note 3: Other FEM may be considered, structure may be modelled with plate elements on which pressure is directly applied (Morison loads may be transferred with a virtual model).

3.3 Short term extrema estimation

3.3.1 Statistical post-processing

Statistical analysis is performed to estimate the short term extreme response of the FOWT.

For each load case, several seeds (time domain analysis, see [3.2]) are performed. Based on the distribution of the extrema of these seeds, the maximum short term response of the FOWT is estimated.

Note 1: The 90% quantile is recommended to evaluate the maximum short term response.

3.3.2 Bootstrap method

A bootstrap method may be used to minimise the uncertainties of the forces on moments calculated from time domain analysis (see [3.2]).

This method is an artificial empirical resampling method implemented by constructing a large number of resampled dataset (bootstraps) from the observed dataset (and of equal size to the observes dataset). Each bootstrap is obtained by random sampling with replacement from the original dataset.

Distribution of the bootstraps are assumed to have the same statistics as the distribution of the whole population of data.

Note 1: This method is possible when the set of observation of the population of the mean up-crossing extrema on the load time series are assumed to be independent and identically distributed.

3.4 Stresses calculations

3.4.1 Based on extrema internal loads in the structure (see [3.3]), stresses are determined in order to check the resistance of the FOWT structure.

Stresses are then compared to criteria given in Sec 5, [4].

3.4.2 Top down analysis

A top down analysis is to be performed on selected details. A time window of 2 or 3 waves periods is selected around the maximum response for each extreme load case.

The detail is loaded with the following conditions:

- displacement and rotations at the boundary nodes are forced from the global model
- inertia efforts are transmitted (gravity and acceleration of the model)
- hydrostatic and hydrodynamic pressures are loaded on the wetted part.

4 Fatigue analysis

4.1 General

4.1.1 General process

The general procedure to fatigue assessment follows generally the following steps:

- Nominal stresses determination
- Geometrical stresses calculation:
  - Hot spot selection
  - Stress Concentration Factor determination.
- Stress cycles counting
- Damage calculation:
  - Short term damage
  - Long term damage.

4.2 Nominal stresses determination

4.2.1 The nominal stresses are to be obtained from an overall structural analysis, for the relevant load cases in accordance with Sec 3.

Spectral analysis may be used. Time domain analysis is to be preferred when both non linearity and dynamic effects are significant. Deterministic analysis may be used when appropriate.

Note 1: Guidance on spectral fatigue analysis methodology for ships and offshore units can be founded in the Guidance Note NI 539.

Note 2: For time domain simulations on global model, simulations of at least 30 minutes are to be run over a selection of load cases.

4.2.2 Sea states selection

Selection of sea states for fatigue analysis is to be done with site specific hindcast data. If no hindcast data are available, site specific scatter diagrams can be used. Each sea state should last at least 30 minutes to catch properly the distribution of cycles.

Note 1: Due to large computation time for sea state, the number of sea state may be small, therefore the choice of these sea states should be chosen carefully.

4.2.3 Wind

For fatigue analysis, wind loads on the rotor are at least to be modelled by times series of forces and moments to catch fatigue induced by wind. The time step of the analysis is to be sufficiently small to catch the wind stresses variations.

4.3 Geometrical stresses (SCF, hot spot)

4.3.1 When not modelled in the overall analysis, geometrical stress concentrations (hot spot) may be accounted for by appropriate Stress Concentration Factors (SCF).

SCF are used to consider geometrical stress concentrations resulting from discontinuities, such as:

- connections
- joints
- eccentricities
- openings,...

4.3.2 Selection of hot spots

Hot spots are selected based on yielding calculation of the structure.

4.3.3 Geometrical stresses calculation

Geometrical stresses (hot spot stresses) are derived from nominal stresses (see [4.2]), multiplied by the SCF.

4.3.4 Stress concentration factor determination

SCF may be obtained from analytical solutions, in some cases, or from adequately calibrated parametric equations or by direct stress analysis.

Local Finite Element Analysis is generally performed on detailed parts of the structure to determined the Stress Concentration Factors. The Society reserves the right to call for such analysis if deemed necessary.

4.3.5 Alternative

For linear materials, the hot spot stresses may also be computed based on a linear combination of forces and moments:

$$\sigma_{HotSpot} = \sum_{\text{structural element}} \sum_i SCF_{a,i} \cdot F_i$$

With:

$SCF_{a,i}$: Ratios of principal hot spot stress, σ_{pr} over unit loads, F_U,

$SCF_a = \sigma_{pr} / F_U$

F_i : Forces or moments.

SCF_a ratios may be determined by Finite Element Analysis: a t*t mesh is done around the detailed part of the structure (Hot spot). Principal stresses, σ_{pr}, are computed in the local FE model loaded with unit loads, F_U, apply at the boundary of the FE model, other extremities remained clamped.

4.4 Stress cycles counting

4.4.1 For each load case, the stress spectrum is determined considering each geometrical stresses (see [4.3]).

For each stress range level $\Delta\sigma_i$, the number of cyles, n_i, is determined $\{(\Delta\sigma_i ; n_i)\}$.

Note 1: A rainflow counting algorithm may be used to determine stress cycles

4.5 Short term damage

4.5.1 For each stress range level $\Delta\sigma_i$ (see [4.4]), the number of cycles before failure, N_i, may be determined using an appropriate S-N curve. Then the cumulative short term damage is calculated as per [4.5.2].

4.5.2 Cumulative short terme damage, D_{ct}

The cumulative short term damage, D_{ct} may be calculated using the Palmgren-Miner rule:

$$D_{ct} = \sum_i \frac{n_i}{N_i}$$

with:

n_i : Number of cyles associated to level i, see [4.4]

N_i : Number of cycles before failure associated to level i.

4.5.3 S-N curves

S-N curves may be used to determined the number of cycles before failure. S-N curves are to be properly chosen, taking into account joint classification, thickness effect and the degree of corrosion protection.

4.6 Long term damage

4.6.1 For each load case, based on the short term damage, D_{ct} (see [4.5]), the cumulative long term damage, D_{lt}, is given by the following:

$$D_{lt} = \sum_{n = sea-states} p_n D_{ct,n}$$

with:

p_n : Occurrence associated to sea-state n.

4.6.2 Fatigue damage ratio

The fatigue damage ratio, D_r, is defined as the ratio of design fatigue life, DFL, over the calculated fatigue life, CFL:

$$D_r = \frac{DFL}{CFL}$$

with the calculated fatigue life, CFL, given by:

$$CFL = \frac{T}{D_{lt}}$$

where:

T : Duration considered for damage D_{lt} determination.

Note 1: In general, fatigue damage, D_{lt} is determined as an annual damage. In that case, the fatigue life time is determined in years.

The fatigue damage ratio is to be checked according to criteria given in Sec 5, [5].

SECTION 7 SCANTLING

1 Sub-structure

1.1 General

1.1.1 Scantling is based on structural analysis performed to assess yielding, buckling and fatigue as defined in Sec 5 and Sec 6.

1.1.2 The structural analysis is to consider all relevant load cases, with design conditions and corresponding loads as defined in Sec 3.

External forces or motions and accelerations are to be applied on the structure as input data for the structural design.

1.2 Scantling

1.2.1 The scantling is to be assessed considering successively the different load cases given in Sec 3 and the associated safety factors defined in Sec 5.

1.2.2 The scantlings obtained by applying the criteria given in Sec 5 are net scantlings.

Corrosion addition is to be added to the net scantling to obtain the gross thickness. The applicable corrosion additions are given in Sec 2.

1.2.3 Plating

Scantling of hull plating is to be assessed against yielding and buckling with criteria stated in Sec 5.

1.2.4 Ordinary stiffeners

Scantling of ordinary stiffeners is to be assessed against yielding and buckling with criteria stated in Sec 5.

1.2.5 Primary supporting members

Scantling of primary supporting members is to be assessed against yielding and buckling with criteria stated in Sec 5.

For primary supporting members, loads are to include global effects, when relevant.

2 Top-structure

2.1 General

2.1.1 The scantling of the tower, rotor, blades, and nacelle are not covered by this Note. However, the input data required for the performance of these scantlings are to be obtained according to this Note.

SECTION 8 STATION KEEPING

1 General

1.1 Application

1.1.1 The purpose of this Section is to provide recommendations related to the design of the station keeping system of a FOWT.

1.1.2 Station keeping can be provided by use of catenary or taut mooring lines system, Tendon Legs System and dynamic positioning.

1.2 Mooring Lines Systems

1.2.1 The design of the mooring system is to be in accordance with the requirements of NR493. Deviations applicable to a FOWT are described in this Section.

1.3 Tendon Legs Systems

1.3.1 The design of the Tendon Legs System is to be in accordance with the requirements of the Section 6 of NR578. Deviations applicable to a FOWT are described in this Section.

2 Design of Mooring lines

2.1 Methods of evaluation

2.1.1 Different methods are presented in NR493.

Quasi-static, quasi-dynamic and fully coupled analysis are described. All these methods are only valid under specific assumptions. For FOWT, the compliance with some of these assumptions may not be always verified. Thus, the type of analysis to be used must be chosen carefully.

Great care is to be paid to the possible interference occurring between low frequency and wave frequency motions. NR493 give the following criteria for compliance with the assumptions of uncoupling: the natural period of the mooring system in surge, sway and yaw is to be greater than five times the zero-up crossing period of the wave.

$T_0 > 5 \times T_z$

Where:

T_0 : Largest natural period of the system for motions in the horizontal plane, in s

T_z : Zero-up crossing period of the wave spectrum in s.

Moreover, out-of-planes motions may not be negligible for such structures as FOWT. In this case, an uncoupled quasi-dynamic analysis may not be relevant.

The line dynamic may also have a major influence on floating bodies such as FOWT. In this case, fully coupled dynamic analysis is to be conducted.

2.2 Design conditions

2.2.1 General

As stated in the NR493, the design tension and offset are to be calculated from all relevant design conditions, i.e. the possible combinations of metocean parameters and configurations of the system.

2.2.2 Configurations of the system

The intact and one-line damaged conditions have to be separately analyzed.

A transient analysis may be required if the FOWT is moored close to the electrical substation or all other critical installations.

NR493 fully describes the methods to analyze intact, damaged and transient conditions.

For station keeping system without redundancy, damaged cases may not be considered, providing that higher safety factors applied, as specified in [2.7.1].

2.3 Environment and actions

2.3.1 General

Wave drift loads, wind and current loads are to be taken into account in the analysis. Descriptions and computation methods are described in NR493.

Environmental conditions and loads to consider are detailed in Sec 3 and App 3.

2.3.2 Wind Action

Action due to wind is a key issue for mooring analysis of FOWT. Great care is to be paid to the consideration of the drag forces due to the wind actions such as rotor thrust and drag on blades, hub and top structure.

2.3.3 Damping

Regarding damping, model tests are to be conducted in order to properly estimate damping effects. As described in NR493, damping due to line and bottom friction can be estimated from dynamic calculations.

2.4 Design Tensions

2.4.1 Line response

For FOWT, interferences between low frequency and wave frequency motions can occur. Moreover, the line dynamic is often not negligible.

The type of analysis to be performed for calculating the line response is to be chosen with consideration for these effects.

2.4.2 Design tensions

Requirements to consider for the calculation of the design tension for each sea state are given in NR493.

2.5 Design Offsets

2.5.1 For FOWT, offsets can be an important issue. Great care must be paid to offsets calculations when other structures are in close proximity.

2.5.2 Methods for design offsets calculations are presented in NR493.

2.6 Fatigue analysis

2.6.1 General

For fatigue analysis, a series of metocean conditions that are representative of the long term conditions at the intended site, or for the intended operations, are to be considered.

For each condition selected, the fatigue damage in each segment or component of the lines, is calculated by the Miner sum, taking into account the fatigue capacity as described in NR493 and the duration of the sea-state.

For fatigue analysis, both low frequency and wave frequency damages have to be taken into account.

2.6.2 In/out of Plane Bending (IPB/OPB)

Fatigue damage due to OPB and IPB is to be assessed as described in NR493.

A complete methodology to evaluate top chain combined fatigue including damage due to OPB and IPB is presented in the guidance note NI 604.

2.7 Criteria

2.7.1 Definitions of safety factor

The safety factor SF of the mooring line components is defined as below:

$$SF = \frac{BL}{T_{max}}$$

Where:

BL	:	Catalogue Breaking Load of the mooring line component
T_{max}	:	Maximum tension occurring over the mooring line component length when design tensions, as determined in [2.4].

For drag anchors, the safety factor SF is defined as below:

$$SF = \frac{MHP}{Ta_{seabed}}$$

Where:

MHP	:	Maximum Holding Power applicable to the mooring site
Ta_{seabed}	:	Tangent-to-the-seabed component of the tension in line at the anchoring point when the design tension is applied to the fair lead.

The perpendicular-to-the-seabed component of the load applied to a drag anchor when the line is submitted to its maximum tension (included damaged condition tensions) at fair lead, should remain less than 20% of its wet weight projected onto the same direction.

Details about safety factors for pile driven anchors can be found in NR493.

2.7.2 Minimum required safety factor

The calculated SF for line components are not to be lower than the values given in Tab 1.

The calculated SF for drag anchors are not to be lower than the values given in Tab 2.

The safety factors for anchor piles, suctions piles and vertical load anchors are defined in NR493. The 20% increase to be considered for systems without redundancy also apply for these types of anchors.

Table 1 : Minimum required safety factor for line components

Condition of the system **(1)**	Dynamic analysis **(3)**
Intact **(2)**	1,67
Damaged	1,25
Transient	1,20

(1) For fiber ropes the safety factor is to be increased in the rope itself (i.e. not including other parts of the line) by 10% for polyester ropes, and 20% for other materials.

(2) For system without redundancy, the safety factor is to be increased by 20%.

(3) For Quasi-dynamic analysis, refer to NR493.

Table 2 : Minimum required safety factor for drag anchors

Condition of the system	Dynamic analysis **(2)**
Intact **(1)**	1,50
Damaged	1,05
Transient	1,05

(1) For system without redundancy, the safety factor is to be increased by 20%.

(2) For Quasi-dynamic analysis, refer to NR493.

2.7.3 Fatigue

The minimum fatigue safety factors to be applied are defined in NR493.

3 Tendon Legs System (TLS)

3.1 Design principles

3.1.1 TLS components

NR578 described design principles of TLS mechanical components. In particular, all components are to be designed, as far as possible, such that their failure will not induce progressive failure of the TLS. Non-redundant system may also be considered providing that higher safety factors applied, as specified in [3.2.4].

Specific components such as top and bottom connectors have to be design to perform several functions, as explained in NR578, Sec 6.

3.1.2 Materials

Several materials can be used for TLS construction such as Metallic and elastomeric materials. In addition to NR578 requirements, the provisions of API RP 2T are to be considered.

3.1.3 Design life

TLS service life is to be at least equal to design life of the FOWT.

3.2 Loading conditions and load cases

3.2.1 Loading conditions

TLS is to be investigated under loading conditions as defined in NR578.

3.2.2 Load cases

Load cases consist in a combination of design loads and load parameters applicable for a specified loading condition.

As detailed in NR578, Sec 4, the following load cases are considered as a minimum for the check of tension legs system:

- maximum tensions
- minimum tensions in tendons
- maximum flex element angle in top and bottom connectors
- maximum loading of specific components (joints, connectors parts), defined on a case-by-case basis.

3.2.3 Tendon analysis

Static loads are to be calculated from the equilibrium condition of the FOWT. NR578, Sec 6 fully described the several effects to take into account in the calculations.

Dynamic loads due to FOWT motions are to be calculated from the hydrodynamic global behavior. Depending on the type of analysis used, a separate tendon analysis may be required.

3.2.4 Damaged case

As per mooring lines, systems without redundancy may be considered providing increased safety factors.

The minimum safety factors to be applied are given in Tab 1.

3.3 Minimum and maximum tendon tensions

3.3.1 General

Minimum and maximum tensions are to be calculated taking into account provisions of API RP 2T and NR578, App 1.

3.3.2 Minimum tension criteria

Minimum tension criteria is to be checked for the design loading conditions defined in Sec 3.

For extreme and survival conditions, temporary negative tension may be accepted providing many restrictions and dedicated dynamic analysis as described in NR578, Sec 4.

3.3.3 Environmental conditions

Environmental conditions and loads to consider are detailed in Sec 3.

3.4 Tendon pipe

3.4.1 The design of tendon pipe is to comply with the requirements of API RP 2T and NR578.

3.5 TLS components

3.5.1 General

TLS components such as top and bottom connectors, joints and flex elements are to be verified according to the requirements of NR578 and API RP 2T.

3.5.2 Connectors

For the calculations of connectors acting stresses and for strength criteria, refer to API RP 2T methods and safety factors.

3.5.3 Flex element

Specific recommendations for flex elements to be applied are detailed in NR578, Sec 6.

3.6 Fatigue of TLS

3.6.1 All parts of tendon legs system are to be checked for fatigue.

3.6.2 Requirements and methods for fatigue calculations have to comply with the requirements of NR578 and API RP 2T.

SECTION 9 FOUNDATION

1 General

1.1 Application

1.1.1 This Section provides general guidance on foundation for FOWT and soil investigations.

1.2 Rules

1.2.1 General

In addition to the guidance given in this Section, the foundations of FOWT are to meet requirements of NI 605.

1.2.2 Special requirements for TLP

Special requirements for foundations of TLP are given in NR578, Sec 7.

2 Soil investigations

2.1 General

2.1.1 It is recommended to perform relevant soil investigations to evaluate risks related to uncertainties on the properties of soils and rocks on site.

Consistent soil data are to be provided for all phases of the life cycle of the FOWT. Major technical risks (seismicity, sand wave motions, scouring,...) are to be determined thanks to soil investigations.

Detailed data for the mitigation of these risks are to be provided for foundation design.

2.1.2 Soil investigations are under the responsibility of the party applying for the certification.

Only guidance are given, recommendations from geotechnical expert prevail.

2.1.3 Soil investigations are to be in accordance with recognized standards.

Note 1: FOWT is classified under geotechnical category 3, when EN 1997 Eurocode 7: Geotechnical design, is used.

2.1.4 Design soil data are to be based on extensive soil investigations, which are generally based on the following phases:

a) Geological desk studies: identify general geological characteristics such as bedrock, soil formations and sedimentation process.

   This preliminary phase takes a particular importance as it determines indication for geophysical surveys.

b) Geophysical surveys: indirect method, such as sonars, seismic or echo sounding equipment.

   Geophysical surveys give a general overview of the ground conditions and are essential to determine properly the location and type of geotechnical surveys.

c) Geotechnical surveys: based on in-situ penetration tests, core sampling and laboratory tests.

2.1.5 The detailed Soil Survey reports and Design Soil data are to be provided for review.

2.1.6 Extent of soil investigation

Extent of soil investigation is to be carefully defined in order to avoid further soil investigation campaign or structure over-dimensioning at detailed design stage due to a lack of soil information collected during initial survey campaign.

The extent of required soil survey depends on the type and the size of foundation retained for the FOWT design and should consider the complexity of the soil and the sea bed.

Note 1: Tolerances for the installation on site of the FOWT are to be taken into account for the definition of the extent of soil investigation.

2.2 Geophysical survey

2.2.1 Geophysical surveys are based on sea bottom and sub bottom surveys. They identify heterogeneous or problematic ground conditions.

It is recommended to conduct geophysical surveys with a great attention as results and findings will generally determine the type, location and number of geotechnical surveys.

2.2.2 Sea bottom surveys

Sea bottom surveys identify bathymetry, and obstacles on the seabed, such as rock outcropping, existing metallic objects, cables, ordnance or wrecks.

Note 1: Before each geotechnical survey, presence of ordnance or cables is to be excluded around location of boreholes and probes.

2.2.3 Sub bottom surveys

Sub bottom survey identify the soil stratigraphy, in particular soil main layers faults, depth of rock layer, outcropping and gas pockets.

2.3 Geotechnical survey

2.3.1 Geotechnical surveys are based on field investigations and laboratory tests. They recover samples of sediments (boreholes) for laboratory testing and perform tests to determined soil mechanical characteristics.

2.3.2 As a good practice, location of each geotechnical investigation is identified on bathymetric and sub-bottom profiling maps in order to interpolate soil conclusions of geotechnical surveys within the field.

Further investigations may be taken depending on the findings during investigations. Suggestions may concern for example: the location, depth of borehole or additional soil boring.

Note 1: Geotechnical surveys are generally based on results from geophysical surveys, as defined in [2.2].

2.3.3 Soil homogeneity

Investigations depend on soil homogeneity. When soil conditions can be considered as homogeneous, only one CPT (cone penetration test) per foundation is requested. However, when soil conditions are inhomogeneous (or complex), additional investigations may be required.

2.3.4 For wind farm, in addition to [2.3.3], a minimum of one investigation per corner and one in the center of the area covered by the wind farm may be recommended when soil conditions are homogeneous.

3 Foundation design

3.1 General

3.1.1 The foundation design is to be based on design soil data obtained from site investigations as described in [2].

General requirements are given in NI 605, Sec 3.

SECTION 10 MARINE SYSTEMS

1 General

1.1 Application

1.1.1 This Section provides general guidance on marine systems of the FOWT.

It covers essentially bilge system and ballast system.

2 Bilge system

2.1 Principle

2.1.1 General guidance for bilge system is given in Offshore Rules, Pt C, Ch 1, Sec 7.

2.1.2 General

An efficient bilge pumping system is to be provided, capable of pumping from and draining any watertight compartment other than a space permanently appropriate for the carriage of fresh water, water ballast, fuel oil or liquid cargo and for which other efficient means of pumping are to be provided, under all practical conditions.

Note 1: Bilge system is not intended at coping with water ingress resulting from structural or main sea water piping damage.

2.1.3 Availability of the bilge system

The bilge system is to be able to work while the other essential installations of the FOWT, especially the fire-fighting installations are in service.

2.2 Design of bilge system

2.2.1 General

The bilge pump system is to consist of pumps connected to a bilge main line arranged as to allow the draining of all spaces mentioned in [2.1].

2.2.2 If deemed acceptable by the Society, bilge pumping arrangement may be dispensed within specific compartments, provided the safety of the FOWT is not impaired.

2.2.3 Prevention of inadvertent flooding

The arrangement of the bilge pumping system is to be such as to prevent the possibility of water passing from the sea and from water ballast spaces into dry compartments, or from one compartment to another.

3 Ballast system

3.1 Principle

3.1.1 Availability of the ballast system

The ballast system is to be able to work while the other essential installations of the FOWT, especially the bilge and the fire-fighting installations, are in service.

The ballast system is to be so arranged that any ballast tank can be ballasted and deballasted by means of two independent pumps.

3.2 Design of ballast system

3.2.1 Prevention of inadvertent flooding

The arrangement of the ballast pumping system is to be such as to prevent the possibility of water passing from the sea and from water ballast spaces into dry compartments, or from one compartment to another.

3.2.2 Column stabilized unit

For column stabilized unit, the ballast system is to be arranged so that the transfer ballast water from one tank to any other tank through a single valve is not possible, except where such a transfer could not result in moment shifts leading to excessive angles of roll or pitch.

3.3 Control and monitoring

3.3.1 Control of ballast pumps and valves

Ballast pumps, ballast tank valves and sea chest valves are to be provided with means of remote control.

3.4 Ice condition

3.4.1 Water freezing prevention

If relevant, the ballast tanks are to be provided with suitable devices to prevent the water from freezing, which is to be designed as to avoid any ice formation in the tank which may be detrimental to the tank. For that purpose, the following may be accepted:

- heating systems by heating coils within ballast tanks
- internal circulating/pumping systems
- bubbling systems
- steam injection systems.

3.4.2 Discharge valves freezing prevention

Suitable protection is to be provided for side ballast discharge valves, ballast tank vent heads, as well as for ballast overflows where existing.

APPENDIX 1 LIFE CYCLE

1 General

1.1 Application

1.1.1 Transportation, installation and specific maintenance phases are not covered by the Society, this Appendix gives only information about these different stages.

Related recommendations provided in this Appendix are to be considered as guidance only.

1.2 Rules and standards

1.2.1 Society Rules

Provisions of the following Rules can be applied for FOWT:

- Offshore Rules
- NR595, Classification of Offshore Handling Systems.

1.2.2 Other standards

Provisions of the following standards can be applied for FOWT:

- ISO 19901-6 - Petroleum and natural gas industries - Specific requirements for offshore structures - Part 6: Marine operations
- IEC 61400-22 - Wind turbines - Part 22: Conformity testing and certification
- API RP 2A WSD - Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design
- IEC 61400-3-2 - Wind Turbines - Part 3: Design requirements for floating offshore wind turbines (Draft)
- ISO 29400 - Ships and marine technology — Offshore wind energy — Port and marine operations.

1.3 Risk assessment

1.3.1 A risk assessment covering the different phases of the FOWT life, such as transportation, installation, commissioning, maintenance, inspections or decommissioning, should be conducted by the Client to identify hazardous situations and appropriate preventive measures or mitigation means. The risk assessment documents are to be submitted to the Society for information.

1.4 Safety

1.4.1 Weather windows for site accessibility

As FOWT tend to be located in energetic environments suitable for energy extraction (high wind), conducting marine operations with acceptable weather conditions may be challenging.

Particular care should be taken to ensure that specific thresholds for access and operation, such as wind and significant wave height, are respected during sea transportation, installation, commissioning, maintenance and inspection phases.

Access should be limited if the conditions to conduct marine operations are unsafe.

1.4.2 Onshore operations

Specific parts of the FOWT may be lifted out of the water and brought ashore prior to conduct inspections or maintenance activities due to limited safe access for inspection and in-site working.

1.4.3 Locking of moving parts

All moving parts of the FOWT resulting in potential hazards during marine operations should be secured from unintentional movement, being locked in a safe position.

1.4.4 Emergency procedures

During marine operations, particular attention should be paid to safety of the operating personnel and appropriate emergency procedures should be developed.

1.4.5 Navigation

Access to the FOWT site may be restricted to external vessels during specific marine operations such as installation, commissioning, maintenance, inspections or decommissioning.

1.4.6 Signalisation

Appropriate lighting and marking should be implemented on the FOWT site, to ensure that the marine operations are performed in safe conditions.

1.5 Lifting

1.5.1 Lifting, in air and in water, may meet the applicable requirements of API RP 2A WSD and of other recognized standards when relevant.

1.5.2 Lifting forces can be imposed on the FOWT by erection lifts during the fabrication, installation and maintenance phases. The magnitude of such forces should be determined through the consideration of static and dynamic forces applied to the structure during lifting and from the action of the structure itself.

Lifting forces on padeyes and on other members of the structure should include both vertical and horizontal components, the latter occurring when lift slings are other than vertical. Vertical forces on the lift should include buoyancy as well as forces imposed by the lifting equipment.

1.5.3 Padeyes intended for lifting operations should meet the design requirements of NR595, App 1.

The design load on the padeye, PL, should consider the dynamic factors, uncertainties related to the cargo and consequence of member failure, as defined in the applied Rule or Standard.

In particular, the following may be considered:

- uncertainties about the cargo mass or centre of gravity location
- skew load due to uncertainties on the sling length or fabrication tolerances
- structural consequence factor, if any
- influence of cargo self-motions
- influence of external conditions
- level of Non Destructive Testing applied on the padeye.

1.5.4 Cranes, hoists and lifting equipment, including all slings, hooks and other apparatus, should be periodically tested and approved for safe lifting.

2 Manufacturing

2.1 General

2.1.1 Survey of construction is performed on the basis of general provisions of Offshore Rules, and particularly Offshore Rules, Pt B, Ch 3, Sec 6.

2.1.2 Documentation

The necessary documentation of manufacturing processes, testing procedures, quality control, plans of the fabrication plants is to be provided to the Society.

A detailed inspection plan should then be agreed between the manufacturer and the Society, prior to the inspection, for the manufacturer to take adequate measures to allow access to the necessary premises.

2.2 Construction survey

2.2.1 The exact extent and scope of the inspections to be carried out is to be defined on a case by case basis in agreement with the Society. As a general rule, the manufacturing inspection of a given component may include:

- survey of the manufacturing of at least one specimen, this survey will cover all the phases of the fabrication process, including the non-destructive testing (NDT) when applicable and the packaging and storage
- verification that design specifications are properly documented in workshop drawings, workshop instructions, purchase specifications, fabrication methods and procedures, including in particular special processes, and welding and NDT procedures when applicable
- review of the fabrication equipment and personnel qualifications, in particular for welders, NDT operators and quality inspectors
- review of the material certificates
- verification of the inspection and test plan and effectiveness of its application
- witnessing of third party supplier Factory Acceptance Testing to ensure the integrity of critical components
- random checks of the effectiveness of acceptance procedures for purchased components
- random checks of manufacturing and testing processes.

2.2.2 Each inspection is to be reported in a detailed inspection report listing all observations and comments raised by the Surveyor.

2.3 Quality system evaluation

2.3.1 The manufacturing evaluation presupposes that the manufacturer quality system is certified to be in conformance with ISO 9001. This system certification is to be carried out by an accredited body that operates according to ISO/IEC 17021.

2.3.2 If the quality system is not certified, an audit is to be performed by the Society to evaluate the quality system of the manufacturer.

3 Transportation and Installation

3.1 Documentation

3.1.1 Transportation manual

Transportation procedures documented in the transportation manual are to be provided to the Society for information.

The description of the transportation process may include:

- technical specifications for the transportation
- limiting environmental conditions
- safety instructions
- transportation arrangement including required fixtures, tooling and equipment
- transportation loads and load conditions.

Note 1: Transportation manual is to be submitted to an appropriate third party for approval.

3.1.2 Particular documentation may be required in case of towing of the FOWT from the installation harbour to the site. Provisions of Offshore Rules, Pt D, Ch 1, Sec 1, [1.7] may be considered.

3.1.3 Installation manual

Installation procedures documented in the installation manual are to be provided to the society for information.

Note 1: Installation procedures are to be submitted to an appropriate third party for review, to ensure compatibility with the site conditions and the FOWT design.

The installation manual may include:

- personnel qualifications and skills
- interface points and any required technical specifications for civil and electrical construction works
- specialized tooling and required lifting fixtures or equipment
- limiting environmental conditions
- quality control check points, measurements and inspections, required by the design
- installation loads and load conditions
- description of safety instructions and planned environmental protection measures
- quality recording and record keeping processes.

3.1.4 Installation tolerances

Installation tolerances are to be specified in the installation procedures, and duly taken into account in design calculations

3.2 Transportation and installation survey

3.2.1 Surveys include attendance of operations at site by the surveyor of the Society, following an agreed program.

3.2.2 Survey of transportation and installation phases is to be performed by an appropriate third party by audit or inspections to verify that the procedures listed in [3.1.1] and [3.1.3] are correctly implemented.

Attendance of a Surveyor during transportation and installation will be decided at the convenience of the Society, in order to ensure that the structure and systems are in apparent good condition after transportation or installation stages, without visible damage.

3.2.3 Transportation survey

The scope of the transportation survey is limited to the transportation from the installation harbour to the site.

3.2.4 Installation survey

The installation survey includes, but not limited to, the following operations:

- installation of anchors
- deployment of mooring lines
- test loading of anchor and lines
- connection to floating platform and tensioning
- post-installation inspection of the system
- reviews and surveys, especially:
  - conformity of all components as attested by Inspection Certificates
  - integrity of installed parts
  - conformity to design of the system as installed.

3.2.5 The surveyor of the Society reviews records and other documentation of the installation operations, prior to the delivery of a Certificate.

4 Commissioning

4.1 General

4.1.1 The purposes of commissioning survey are:

- to ensure that the procedures described in the commissioning manual are compliant with the requirements of the manufacturer, the design basis and applicable standards
- to verify that the final commissioning of a FOWT installed in a specific project at a specific site is actually carried out according to these procedures.

4.1.2 Commissioning manual

Before commissioning, instructions documented in the commissioning manual are to be submitted to the Society for review.

The commissioning manual is to include at least:

- procedures to commission the FOWT
- test plans to be followed to verify that all components of the FOWT operate safely.

Note 1: This part is only necessary if the commissioning manual has not already been approved as part of the type certification of the FOWT.

4.1.3 Final commissioning report

The commissioning survey is to be followed up by a final commissioning report to be approved by the Society.

4.2 Commissioning survey

4.2.1 The commissioning is to be attended by the Society to ensure safe operation of the FOWT, including at least the following checks:

- functional tests and test of the safety system: normal start-up, normal shutdown, emergency shutdown, behaviour at loss of load, behaviour at overspeed, function test of the protection system
- general appearance and check for damage, in particular due to transportation or installation phases
- checking of the control system settings
- corrosion protection.

4.2.2 Sampling principle

The first series of FOWT to be commissioned is to be inspected by the Society, after which the commissioning survey may be not be systematic but based on random sampling. The exact sampling rate will be determined on a case by case basis, depending among other parameters on the findings from the first round of inspections.

In addition to these inspections, all commissioning reports for the FOWT whose commissioning has not been attended are to be reviewed by the Society. Any deviation from the intended procedures is to be justified, and may involve subsequent inspections.

5 Maintenance, inspection and test plan

5.1 Documentation

5.1.1 Maintenance manual

Maintenance instructions documented in the maintenance manual are to be submitted to the Society for information.

The maintenance manual may include:

- scheduled maintenance actions including inspection intervals and routine actions
- personnel qualifications and skills
- required specialized tooling, spare parts and personal protection equipment
- access procedures
- limiting environmental conditions
- description of the FOWT and of its major components
- start-up, shutdown and re-commissioning procedures
- diagnostic procedures and trouble-shooting guide
- lifting loads and load conditions, when relevant
- repair instructions
- inspection for marine growth and its removal
- maintenance of the scour protection system
- maintenance of the corrosion protection system
- emergency procedures
- safety instructions and planned environmental protection measures
- quality recording and record keeping processes.

5.1.2 Inspection and test plan

A site-specific inspection and test plan is to be submitted to the Society for review.

The inspection and test plan is to include at least:

- the components to be inspected
- the type of inspection (visual inspection, NDT, inspection of the submerged structures, etc.)
- the sampling rate
- the recurrence of the inspection
- the qualification of the personnel performing the inspection.

5.1.3 Along the life of the FOWT, the maintenance manuals as well as the inspection and test plan may be updated in order to take into account the accumulated field experience. Any revisions of these procedures is to be submitted to the Society for review.

5.2 Maintenance survey

5.2.1 The FOWT is to be periodically inspected by the Society to check that the procedures described in the maintenance manual and in the inspection and test plan are correctly followed.

The components covered by inspection may include:

- rotor blades
- drive train, including the gearbox if applicable
- generator
- electrical installations
- safety and control systems
- locking devices and mechanical brakes
- main structural components (hub, nacelle frame, etc.)
- support structure including foundations
- corrosion protection system
- scour protection system, if applicable.

5.2.2 The interval between inspections is determined on a case-by-case basis depending in particular on the FOWT design, previous experiences with similar technologies and the results of previous inspections.

Note 1: As a guidance, a typical 5-years interval may be considered.

5.2.3 In addition to these inspections, maintenance reports and records of damage and repairs that may have occurred are to be reviewed annually by the Society.

Any outstanding issue is to be properly documented as well as the actions undertaken to resolve it. All modifications of the original design is to be reported without delay to the Society for evaluation.

6 Decommissioning

6.1 General

6.1.1 A decommissioning program is to be submitted to the appropriate local and/or national authorities responsible for the deployment site.

The decommissioning program is to be compliant with relevant local and/or national regulations, having particular regard to the requirements imposed by environmental licensing authorities.

APPENDIX 2 HYDRODYNAMIC

1 General

1.1 Introduction

1.1.1 This Appendix discusses the issues related to the loading and responses of the FOWT under hydrodynamic loading, especially under waves and current.

The main accent is put on hydrodynamic calculations which represent the basis for the assessment of the hydrodynamic, mooring, and structure calculations.

The necessary numerical methods are discussed and guidance is given for their use in the context of different FOWT design issues.

1.1.2 Main hydrodynamic issues

The non exhaustive list of main hydrodynamic issues is given by the followings:

- offset and set down
- maximum yaw motion
- mooring line/tendon tension
- deck clearance and wave run-up
- accelerations
- internal loads in the hull structure
- pressures.

1.1.3 Particularities of FOWT

Compared to usual offshore units, FOWT are relatively small body, the wave loads are then non linear.

2 Hydrodynamic analysis

2.1 General

2.1.1 Several hydrodynamic approaches exist:

- Morison method, see [2.2]
- potential flow hydrodynamic approach based on wave diffraction-radiation models, see [2.3]
- CFD (Computational Fluid Dynamics) methods based on solving Navier Stockes or Euler equations (not very used often but helpful for some particular local application such as non linear wave run-up, wave overtopping, impact on deck...).

2.1.2 The choice of hydrodynamic approach is generally determined by the structure dimension and the wave length:

- Morison method for slender structure, see [2.2]
- Diffraction-radiation theory for large structure, see [2.3].

Note 1: For medium structure, a combination of Morison method and diffraction-radiation theory is generally used.

2.2 Morison method

2.2.1 The Morison method is a simple method but its domain of validity is limited. This method can be efficiently used for slender structures only.

Main diffraction - radiation effects are not taken into account. There is no possibility to include higher order diffraction effects. Good point is that the non linear forces can be included.

Morison model cannot be applied for the vertical forces on tapered parts and on bottom surface of the structure from the undisturbed wave field (Froude Krylov force).

2.2.2 Slender structure

A structure may be considered as a slender structure when the structural cross section is significantly smaller than the considered wave length.

The criteria considered to define a slender structure is given by:

$$\frac{\lambda}{D} > 5$$

where:

λ : Wave length, in m

D : Structure diameter, or projected cross-sectional dimension of the structure, in m.

Note 1: A slender structure does not significantly modify the incident wave. Main diffraction-radiation effects may be neglected.

2.2.3 Principles

Morison method is based on the so called strip approach where the structure is cut into a certain number of regular sections on which the forces are calculated by relating the local geometry and the fluid kinematics (velocities and accelerations) though the Morison formula.

2.2.4 Morison's formulation

Morison force, F_M, is given by the following formula:

$$F_M = \frac{1}{2}\rho_w C_D D\left(v_F - \frac{d\xi_B}{dt}\right)\left|v_F - \frac{d\xi_B}{dt}\right| + \frac{\rho_w \pi D^2}{4}\left[(1 + C_M)\gamma_F - C_M\frac{d^2\xi_B}{dt^2}\right]$$

where:

ρ_w : Water density, in kg/m^3

C_D : Drag coefficient

C_M : Added mass coefficient

D : Structure diameter, or projected cross-sectional dimension of the structure, in m.

v_F : Local fluid velocity, in m/s

ξ_B : Local body displacement, in m

γ_F : Local fluid acceleration, in m/s^2.

Note 1: Usually, model tests are performed to estimate the values of C_M and C_D.

Note 2: Special attention is to be paid on the combination of waves and currents speeds when Morison calculation are performed.

2.3 Radiation-diffraction theory

2.3.1 Radiation/diffraction model is generally performed on large structure for which the global behaviour is dominated by inertia forces.

2.3.2 Large structure

A structure may be considered as a large structure when its characteristic length is similar to the wave length and the diffraction/radiation effects are important.

The criteria considered to defined a large structure is given by:

$$\frac{\lambda}{D} < 6$$

where:

λ : Wave length, in m

D : Structure diameter, or projected cross-sectional dimension of the structure, in m.

Note 1: A large structure significantly modify the wave pattern.

Note 2: Compared to a fixed offshore wind turbine, the large volume of the floating platform of the FOWT may have an impact on the calculation of the hydrodynamic loads.

2.3.3 Principles

The assumptions of the potential flow are adopted.

The usual methods are based on the boundary Integral Equations Method (BIEM) in which the flow field is represented by the distribution of singularities (sources/sinks, dipoles,...) over the wetted part of the structure.

Diffraction and radiation effects are taken into account consistently but viscous drag is missing. The method can be used for linear (first order), weakly non linear (second order), and fully non linear calculations.

Note 1: Due to their complexity, the fully non linear calculations are usually employed only for very special purposes.

Note 2: Linear calculations are prerequisite for the second order calculations, and the second order calculations are not be performed if linear problem is not solved properly.

Note 3: Viscous effects may be introduced by Morison formulation in combination with potential theory as defined in [2.4].

As a first approach, the FOWT is generally considered a a rigid body. However, hydro elastic effects are to be considered where appropriate.

The radiation/diffraction model can be applied in frequency or in time domain. Usual practice is to apply it in frequency domain and for some specific application use the hybrid frequency/time approach.

2.3.4 Diffraction

For large structure, diffraction can be important. As diffraction can induce significant perturbations of the wave pattern, it is important to introduce the boundary condition of no flow through the diffracting structure.

Note 1: Morison's equations as defined in [2.2] are not applicable to take into account the diffraction effects.

Second order (or higher order) potential flow theory can be used to calculate diffraction effects.

For TLP, special attention is to be paid on springing and ringing excitation.

2.3.5 Wave radiation

For large structure, wave radiation can be important. Radiation is induced by motions of the structure and generates free surface waves.

Wave radiation effects, such as added mass and damping, can be calculated by potential flow theory.

Note 1: Morison's equations as defined in [2.2] are not applicable to take into account the wave radiation effects.

2.4 Mixed model

2.4.1 In some cases, when both slender and large structures are present, the combined diffraction/radiation/Morison model may be necessary. The idea is to use the Morison formula for slender structures by evaluating the fluids kinematics using the radiation-diffraction model.

Due to the nonlinear character of Morison formula, proper linearization is to be performed before solving the motion equations.

2.4.2 Medium structure

Medium sized elements may be modelled by radiation/diffraction and by Morison elements.

2.5 Frequency domain

2.5.1 Analysis in frequency domain is a classical method for hydrodynamic calculations. This approach is based on the hypothesis that the response is linear.

Note 1: The main advantage of the frequency domain is its relative simplicity and the low CPU time requirements.

Note 2: For small floating objects, the assumption of linearity may often be untrue.

2.5.2 Validity

The linear assumption is a good approximation when:

- wave height is not high in absolute and with respect to FOWT draft

Note 1: Ratio wave height/FOWT draft could be important as FOWT are often small object operating at moderate draft.

- viscous effects are not prevailing

Note 2: This assumption is hardly fulfilled for FOWT.

- hydrostatic stiffness in heave is constant with respect to draft variation.

Note 3: Semi submersible platform does not ensure each time a constant heave stiffness.

2.5.3 Due to the small domain of validity for FOWT, the frequency domain approach is generally performed to calculate the input coefficients for the time domain simulation.

2.6 Time domain

2.6.1 The time domain analysis is based on the direct integration in time of the equations of motion which makes possible the inclusion of system non linearities at each time step.

2.6.2 Time domain approach is generally used to determine the high order loads, when the non linear effects are important (e.g. in extreme conditions).

3 Wave spectra

3.1 General

3.1.1 The wave spectrum is a frequency domain description of the sea surface elevation in a sea state and measures the amount of energy associated with the fluctuation of the sea surface elevation per unit frequency band and per unit directional sector.

The wave frequency spectrum is generally given by use of some parametric form as:

- Pierson Moskowitz
- JONSWAP (JOint North Sea WAve Project)
- Ochi Bubble or
- Torsethausgen wave spectrum.

Note 1: The area under the wave spectrum is the zeroth spectral moment m_0 which measure the total energy in the sea state.

3.1.2 Spectral approach

Where the spectral approach is used, the design sea states are to be specified by their significant wave heights H_s, mean zero up-crossing period T_z (or spectral peak period T_p), together with adequate formulations of spectral energy distribution, and spectral dispersion in direction.

3.1.3 Spectrum models

Choice of spectrum model depends on the type of sea. As a general guidance, spectral model corresponding to the sea state may be found in Tab 1.

In some areas, it may be relevant to split the incoming energy (waves) in two, or more, parts (e.g. swell and wind sea), modelled by two, or more, spectra with different direction of approach.

Note 1: One peak power spectral density model may be sufficient for wind generated sea, but when swell are also present, these are to be represented by a second power spectral model adapted to this kind of waves, it results in a double peak spectral model.

Table 1 : Wave spectra

	Wind generated waves		Wind sea	Swell
	Fully developed	Developing		
JONSWAP **(1)**		X		
Pierson - Moskowitz	X			
Ochi Bubble **(2)**			X	X
Torsethausgen **(2) (3)**			X	X
(1) May be insufficient for FOWT **(2)** Double peak spectral model **(3)** Developed for North Sea conditions				

APPENDIX 3 EXTERNAL CONDITIONS

1 General

1.1 Scope

1.1.1 This Appendix provides general guidance relating to the external conditions which may affect the design of the FOWT.

1.1.2 Main external conditions are environmental conditions and electrical power network conditions.

1.1.3 External conditions taken as the basis of the design of FOWT are to be stated in the design documentation.

1.2 Environmental conditions

1.2.1 Environmental conditions are generally defined in terms of wind and waves. Information relating to currents may be requested on a case by case basis.

Environmental conditions are described:

- for wind conditions, in [2]
- for waves conditions, in [3]
- for other marine conditions, in [4].

1.2.2 Normal conditions

Normal conditions are expected to occur frequently during the FOWT's life.

When no limiting parameters are specified by the Designer for various operation of the FOWT, the normal conditions are to be associated with a typical return period of 1 year.

In general, limitation of wind speed and wave height are specified

1.2.3 Extreme conditions

Extreme conditions have a low probability of being exceeded during the life of the FOWT.

For the purpose of this Note, extreme conditions are associated with a minimum return period of:

- 50 years, for floating platform
- 50 years for anchoring system.

Higher return periods may be considered when requested.

Note 1: The return period of 1 year may be required for the design of the top structure, according to IEC 61400-3.

1.2.4 Metocean database

The metocean database is to include the following information:

- wind speed and directions
- significant wave heights, wave periods and directions
- correlation of wind and wave statistics
- current speeds and directions
- water levels
- occurrence and properties of the sea ice
- occurrence of icing
- other relevant metocean parameters.

Metocean database is to be based on site specific measurements.

Note 1: Results are to be correlated with data from nearby site with long term data.

As alternative, numerical simulations could be performed to establish metocean database.

2 Wind

2.1 Wind specification

2.1.1 Symbols

D : Rotor diameter, in m
V_{hub} : Mean wind speed at hub, in m/s
$V(z)$: Wind speed at the height z, in m/s
z : Height above still water level, in m
z_{hub} : Hub height above still water level, in m
I_{15} : Average value of hub height turbulence intensity at $V_{hub} = 15$ m/s
σ_1 : Standard deviation of wind speed as defined in [2.2.3]
Λ_1 : Turbulence scale parameter, in m
Λ_1 is to be taken as:
$= 0,7\ z$ for $z \leq 60$ m
$= 42$ for $z > 60$ m.

2.1.2 Wind data are to be specified for the purpose of overall and local strength analysis and for mooring and stability analysis of the FOWT.

2.1.3 The following wind values are to be given, as 10min average and as function of the wind direction:

- extreme wind speed at hub height with recurrence period of 50 years, V_{e50}
- wind speed probability density function
- ambient turbulence standard deviation
- wind shear
- air density
- annual average wind speed at hub height, V_{ave}

- average inclined flow
- wind speed distribution (Weibull, Rayleigh, measure,...)
- wind direction distribution.

2.1.4 The wind data are to be specified as the wind speed at the hub height and averaged over 10 min.

Note 1: Attention is to be on paid on metocean database: the wind is generally described by mean wind speed at a specified reference height of 10m.

2.1.5 The wind speed over other time intervals and the vertical profiles of wind speed, which are required for the calculation of wind loads are to be derived from the above reference wind speed using recognised relations.

2.1.6 As a guidance, conversion factors between 10-min average wind speed and given average wind speed are given in Tab 1.

Table 1 : Wind conversion factors

Averring period	Correction factor
10 minutes	1,00
1 hour	0,95
3 hours	0,90

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

2.2 Wind conditions

2.2.1 Wind conditions are to be site specific and are essentially represented by:

- wind speed profile V(z)
- standard deviation of wind speed, σ_1
- direction change θ, when relevant.

Note 1: Turbulence intensity of wind speed, I, is given by the following relation: $I=\sigma_1/V(z)$.

Note 2: For RNA, wind conditions may be determined by model specified in IEC61400.

2.2.2 Wind conditions are divided into two categories:

- normal wind conditions
- extreme wind conditions.

2.2.3 Turbulence standard deviation, σ_1

The turbulence standard deviation, σ_1, is to be determined using appropriate statistical methods applied to measured and preferably de-trended data.

Note 1: Estimation of turbulence standard deviation σ_1, given by IEC 61400-3 may be used.

2.2.4 Normal wind conditions

Normal wind conditions occur frequently during the life time of the FOWT. They include:

- normal wind
- operating gust
- wind turbulence
- direction change
- coherent gust with direction change
- wind shear.

Note 1: The normal wind conditions correspond to the wind acceptable for the production of electricity.

Normal wind conditions are described hereunder and sum up in Tab 2.

a) Normal wind

1) The normal wind profile is the description of the average wind speed as a function of the height above the still waterline, given by:

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha}$$

α : Wind shear exponent, generally to be taken as 0,14.

2) Normal turbulence

The normal turbulence is the description of the turbulent wind speed and is defined in term of the standard deviation of turbulence.The normal turbulence is to be applied together with the normal wind profile.

The normal turbulence is defined as the 90% quantile in the probability distribution of wind speed standard deviation conditioned on the 10-min mean wind speed at hub height.

If site assessment are not available, the turbulence standard deviation σ_1, may be given by the following:

$$\sigma_1 = \frac{V_{hub}}{\ln\left(\frac{z_{hub}}{z_0}\right)} + 1,28 \times 1,44 \times I_{15}$$

where:

z_0 : Roughness length, in m

z_0 may be determined by the following formula:

$$z_0 = \frac{A_c}{g}\left(\frac{0,4 \cdot V_{hub}}{\ln\left(\frac{z_{hub}}{z_0}\right)}\right)^2$$

A_c : Charnock constant, taken equal to:

- 0,011 for open sea
- 0,034 for coastal.

b) Operating gust

The operating gust is represented by a time depending wind speed profile, as given by the following:

The gust magnitude at the hub height, V_{gust}, is given by the following:

$$V_{gust} = \mathrm{Min}\begin{Bmatrix} 1,35V_{3s,1} - V_{hub} \\ 0,9\mathrm{Ln}T_g + 1,18 \cdot \dfrac{\sigma_1}{1 + 0,1\dfrac{D}{\Lambda_1}} \end{Bmatrix}$$

where:

$V_{3s,1}$: Wind speed (average over 3 seconds) with return period of 1 year at hub height, in m/s

T_g : Gust time period, in sec.
T_g is to be taken as:

$T_g = \{10,5;\ 1,5T_{surge};\ 1,5T_{sway};\ 1,5T_{heave};\ 1,5T_{roll}\ ;\ 1,5T_{pitch}\ ;\ 1,5T_{yaw}\}$

Gusts with longer durations are to be taken into account if intended to occur at the specific site of the FOWT.

Note 2: Resonance and interaction of gust with the FOWT is possible.

c) Direction change

The extreme direction change is to be applied together with the normal wind speed profile, as defined in [2.2.4] and the extreme direction change magnitude, θ_e, calculated as follow:

$$\theta_e = \pm 4\,\mathrm{atan}\frac{\sigma_1}{V_{hub}\left(1 + 0,1\dfrac{D}{\Lambda_1}\right)}$$

where:

σ_1 : Standard deviation of normal wind speed as defined in [2.2.4].

The transient extreme direction change is given by:

$$\theta(t) = \begin{cases} 0 & \text{for } t < 0 \\ \pm 0,5\theta_e\left(1 - \cos\left(\dfrac{\pi}{T}t\right)\right) & \text{for } 0 \le t \le T \\ 0 & \text{for } t > T \end{cases}$$

where T, the duration of the extreme direction change, is taken equal to 6 seconds.

The sign in the equation is to be chosen such that the most unfavourable transient loading occurs. At the end of the direction change, the direction is assumed to remain a constant value.

d) Coherent gust with direction change

The coherent gut with direction change is to assumed to have a magnitude of:

$V_{cg} = 15$ m/s

$$\theta_{cg} = \begin{cases} 180° & V_{hub} \le 4\,m/s \\ \dfrac{720°}{V_{hub}} & V_{hub} > 4\,m/s \end{cases}$$

Transient wind speed is given by:

$$V(z,t) = \begin{cases} V(z) & t < 0 \\ V(z) + 0,5V_{cg}\left(1 - \cos\left(\dfrac{\pi}{T}t\right)\right) & 0 \le t \le T \\ V(z) + V_{cg} & t > T \end{cases}$$

The rise in wind speed is assumed to occurred simultaneously with direction change:

$$\theta(t) = \begin{cases} 0° & t < 0 \\ \pm 0,5\theta_{cg}\left(1 - \cos\left(\dfrac{\pi}{T}t\right)\right) & 0 \le t \le T \\ \pm\theta_{cg} & t > T \end{cases}$$

where:

V(z) : Normal wind speed profile, as defined in [2.2.4]

T : Rise time, in s
Taken equal to 10 s.

e) Wind shear

The wind shear is divided in vertical wind shear and horizontal wind shear. These are independent and are to be apply separately.

The transient vertical wind shear and transient horizontal wind shear are given by formula given in Tab 2.

2.2.5 Extreme wind conditions

Occur rarely during the life time of the FOWT.

Return periods of 1 and 50 years are generally to be considered.

a) Extreme wind

The extreme wind is the description of turbulent wind with specified return period of 1 and 50 years.

- The extreme wind profile can be represented by:

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha}$$

where α is taken as 0,11.

Note 1: $V_1(z) = V_{hub,1}\left(\dfrac{z}{z_{hub}}\right)^{0,11}$ and $V_{50}(z) = V_{hub,50}\left(\dfrac{z}{z_{hub}}\right)^{0,11}$

- The turbulence of the extreme wind can be represented by the standard deviation of the extreme wind speed, $\sigma_{1,e}$, as follows:

$\sigma_{1,e} = 0,11V_{hub}$

b) Extreme wind turbulence

The extreme wind turbulence is to be applied together with the normal wind profile as defined in [2.2.4] and the turbulence with standard deviation $\sigma_{1,et}$ given by the following:

$$\sigma_{1,et} = 2I_{15}\left(0,072\left(\frac{V_{ave}}{2} + 3\right)\left(\frac{V_{hub}}{2} - 4\right) + 10\right)$$

where:

V_{ave} : Average annual wind speed at hub, in m/s.

Table 2 : Wind conditions

Wind model	V_{hub}	Wind profile	
Normal	$V_{hub} \in [V_{in} ; V_{out}]$	$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0,14}$	$\sigma_1 = \frac{V_{hub}}{\ln\left(\frac{z_{hub}}{z_0}\right)} + 1,28 \times 1,44 \times I_{15}$
		z_0 : Roughness length, in m	
Extreme	$V_{hub,1}$ $V_{hub,50}$	$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0,11}$	$\sigma_{1,e} = 0{,}11 V_{hub}$
Turbulence	$V_{hub} \in [V_{in} ; V_{out}]$	**(1)**	$\sigma_{1,et} = 2I_{15}\left(0,072\left(\frac{V_{ave}}{2}+3\right)\left(\frac{V_{hub}}{2}-4\right)+10\right)$
Direction change	$V_{hub} \in [V_{in} ; V_{out}]$	Direction change: **(1)** $\theta(t) = \begin{cases} 0 & \text{for } t < 0 \\ \pm 0,5\theta_e\left(1-\cos\left(\frac{\pi}{T}t\right)\right) & \text{for } 0 \le t \le T \\ 0 & \text{for } t > T \end{cases}$	$\theta_e = \pm 4 \,\text{atan} \frac{\sigma_1}{V_{hub}\left(1+0,1\frac{D}{\Lambda_1}\right)}$
		T : Extreme direction change time period, is taken equal to 6 seconds	
Operating gust	V_{in} $Vr - 2m/s$ Vr $Vr + 2m/s$ V_{out}	Operating gust profile for $0 \le t \le T$: **(1) (2)** $V(z,t) = V(z) - 0,37V_{gust}\sin\left(\frac{3\pi}{T_g}t\right)\left(1-\cos\left(\frac{2\pi}{T_g}t\right)\right)$	$V_{gust} = \text{Min}\begin{Bmatrix} 1,35V_{3s,1} - V_{hub} \\ 0,9\text{Ln}T_g + 1,18 \cdot \frac{\sigma_1}{1+0,1\frac{D}{\Lambda_1}} \end{Bmatrix}$
		$V_{3s,1}$: Wind speed (average over 3 seconds) with return period of 1 year at hub height, in m/s T_g : Gust time period, in sec, taken as: $T_g = \{10,5; 1,5T_{surge}; 1,5T_{sway}; 1,5T_{heave}; 1,5T_{roll}; 1,5T_{pitch}; 1,5T_{yaw}\}$	
Coherent gust	Vr - 2m/s Vr Vr+ 2m/s	Wind speed profile: **(2)** $V(z,t) = \begin{cases} V(z) & t < 0 \\ V(z) + 0,5V_{cg}\left(1-\cos\left(\frac{\pi}{T}t\right)\right) & 0 \le t \le T \\ V(z) + V_{cg} & t > T \end{cases}$	$V_{cg} = 15$ m/s T = 10 s
		Direction change: $\theta(t) = \begin{cases} 0° & t < 0 \\ \pm 0,5\theta_{cg}\left(1-\cos\left(\frac{\pi}{T}t\right)\right) & 0 \le t \le T \\ \pm\theta_{cg} & t > T \end{cases}$	$\theta_{cg} = \begin{cases} 180° & V_{hub} \le 4 m/s \\ \frac{720°}{V_{hub}} & V_{hub} > 4 m/s \end{cases}$
		T : Rise time in seconds, taken equal to 10 seconds	
Wind shear	V_{in} $Vr - 2m/s$ Vr $Vr + 2m/s$ V_{out}	Vertical shear profile for $0 \le t \le T$: **(1) (2)** $V(z,t) = V(z) \pm \left(\frac{z - z_{hub}}{D}\right)\left(2,5 + 0,2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{\frac{1}{4}}\right)\left(1-\cos\left(\frac{2\pi}{T}t\right)\right)$	
		Horizontal wind shear for $0 \le t \le T$: **(1) (2)** $V(y,z,t) = V(z) \pm \left(\frac{y}{D}\right)\left(2,5 + 0,2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{\frac{1}{4}}\right)\left(1-\cos\left(\frac{2\pi}{T}t\right)\right)$	
		β : Coefficient, taken equal to 6,4 T : Time period, taken equal to 12 seconds	
(1) Otherwise specified, the wind speed is assumed to follow the normal wind profile **(2)** V(z) refers to the normal wind profile			

3 Waves

3.1 Wave specifications

3.1.1 Waves conditions are to be defined for strength and fatigue analysis and for the purpose of air gap determination, if applicable.

Note 1: This Appendix provides guidance on waves. For guidance on hydrodynamic calculation, such as wave models, reference is done to App 2.

3.1.2 The following waves values are to be state in the design documentation:

- Significant wave heights, H_{s1} and H_{s50}, and their associated ranges of wave peak periods (see [3.1.6])
- Maximum wave heights, H_1 and H_{50},and the associated range of wave peak periods.

3.1.3 The wave data are to be specified as the significant wave height and over 3 hours period.

3.1.4 Wave period

The wave period is the time interval between the two zero up-crossings which bound a zero up-crossing wave.

3.1.5 Wave height

The wave height H, is defined as the vertical distance between the highest and lowest points on the water surface of an individual zero up-crossing wave.

For a given design condition of the FOWT, the wave heights are to be specified for a sufficient range of periods, such that the maximum response of the FOWT is properly covered for all sea states liable to be met in such condition.

Directional data are to be considered.

Note 1: Wave height may be limited by water depth.

Note 2: When wave heights follow a Rayleigh distribution, the significant wave heights in a 3 hours stationary sea state, H_{s50} and H_{s1} may be assumed to be given by the following relation:

$H_{50} = 1{,}86H_{s50}$ and $H_1 = 1{,}86H_{s1}$

3.1.6 Significant wave height H_s

The significant wave height H_s is defined as:

- when the sea state is defined by statistical measures of the wave heights:

  H_s is given by $H_{1/3}$ the average height of the highest third of the zero up-crossing waves.

Note 1: In this case, H_s is called the statistical significant wave height.

Note 2: The wave height visually estimated can be considered to correspond to $H_{1/3}$.

- when the sea state is defined by spectrum model:

  H_s is given by H_{m0}, the modal wave height derived from numerical analysis of the spectrum:

  $H_{m0} = 4{,}004\ m_0^{0.5}$

  where:

  m_0 : Variance of the wave spectra.

Note 3: In this case, H_s is called the spectral significant wave height.

Note 4: Well note that in deep water H_{m0} and $H_{1/3}$ are matching, but in shallow waters H_{m0} may be less than $H_{1/3}$.

As a guidance, the extreme significant wave heights with return period of 1 year and 50 years, respectively $H_{s1,}$ H_{s50} may be determined from metocean database according to ISO 19901-1.

3.1.7 Breaking wave

Breaking waves depend the water depth, sea floor slope and wave period. Different breaking waves are considered:

- spilling breakers: waves break slowly as they approach to the shore (flat slope)
- plunging breakers: waves break suddenly by running a sea floor slope (steep slope)
- surging breakers: wave encounter a sea floor slope (very steep or vertical). This type of breaking waves results in a quickly rising and falling water level.

3.2 Wave conditions

3.2.1 Wave conditions are to be site specific and are generally represented by:

- significant wave height, H_s
- spectral peak period, T_p
- wave spectrum, when relevant
- mean wave direction, θ_w, when relevant.

3.2.2 Wave conditions correspond to the description of waves at the intended site of the FOWT. Sea state is given in term of wave height (see Tab 3):

- Normal wave
- Severe wave
- Extreme wave.

3.2.3 Normal wave

The normal wave correspond to the wave height conditioned to the normal wind.

3.2.4 Severe wave

The severe wave corresponds to the maximum wave height, $H_{max,\ prod}$, associated to normal wind condition for which the FOWT is assumed to be in production condition.

If no sea state limitation is specified for the production condition, significant wave height with a return period of 50 years, H_{S50}, can be considered as a conservative value.

Note 1: In fact, the combination of mean wind speed and wave period may have a return period of 50 years.

3.2.5 Extreme wave

The extreme wave corresponds to the wave height associated to a return period of 1 year and 50 years.

Table 3 : Wave conditions

Wave conditions	H_s	Description
Normal	$H_s(V_{hub})$	Significant wave height H_s conditioned on normal wind condition given by mean wind speed V_{hub}.
Severe	$H_{smax,\ prod}$	Maximum operational wave height
Extreme	H_{S1} H_{S50}	Wave height for which the combination with global environment has a return period of 1year and 50 years.
Note 1: For each wave height, the appropriate range of wave period is to be considered. The resultant most unfavourable loading are to be used to design the FOWT.		

4 Other marine conditions

4.1 Current

4.1.1 Current specifications

Current conditions are to be defined for the purpose of load analysis of drag dominated structures and mooring analysis of FOWT.

The following current values are to be given:

- extreme sea surface current velocities with 1 year recurrence period and direction
- extreme sea surface current velocities with 50 year recurrence period and direction.

The current velocities are to be specified taking account the contribution of all relevant components:

- wind generated current
- tidal current
- circulational current
- loop and eddy current
- soliton current
- longshore current.

Unusual bottom or stratified effects are to be clearly stated.

Directional profiles may be considered where applicable.

Note 1: The total current velocity is the vector sum of all components at a given position in the water column

4.1.2 Sub-surface currents

Generally sub-surface currents are assumed to have the same direction than waves. However, currents through the depth including directionality, are to be combined vectorially with the design wave conditions.

Sub surface currents profile $U_{ss}(z)$, may be given by the following power law over the water depth:

$$U_{SS}(z) = U_{SS}(0)\left[\frac{z+d}{d}\right]^{\frac{1}{7}}$$

Where:

d : Water depth, in m.

Note 1: Sub-surface velocity with return period of 1 year and 50 years may be determined from analysis from measurements of components associated with tidal, storm surge, wind generated and wave induced surf currents relevant to the specific site.

4.1.3 Wind generated near-surface currents

The wind generated current may be given as a linear distribution of velocity U_w:

$$U_W(z) = U_W(0) \cdot \frac{1+z}{20}$$

where:

$U_w(0)$: Surface wind generated current velocity:

$U_w(0) = 0{,}01 V_{1hour}(10)$

V_{1hour} (10): 1hour mean value of wind speed at 10 m height above SWL, in m/s

Note 1: Values with return periods may be determined from analysis of appropriate measurements at the intended site.

4.1.4 Breaking wave induced surf current

When the FOWT is located near a breaking wave area, induced surf currents are to be considered.

Breaking wave induced surf currents can be estimated by numerical methods, such as Boussinesq model.

For near shore surf currents, the current velocity at the breaking waves area U_{bw}, can be estimated by the following:

$$U_{bw} = 2s\sqrt{gH_B}$$

where:

H_B : breaking wave height

g : gravity acceleration, in m/s²

s : beach floor slope

Note 1: Near shore surf currents have a direction parallel to the shoreline.

4.2 Water level

4.2.1 Water levels are to be site specific and represented by the following values:

- mean sea level
- highest and lowest astronomical tide
- highest still water level (including positive storm surge)
- lowest still water level (including negative storm surge)
- storm surge with recurrence period of 50 years
- tidal variation.

4.3 Sea ice

4.3.1 For FOWT intended to operate at a site where sea ice can occurred, the following values of sea ice are to be given:

- H_{ice}, ice thickness with 50 year of recurrence period
- ice crushing strength
- risk of current or wind induced ice floe
- risk of forces induced by fluctuating water level
- frequency of ice concentration.

4.4 Marine growth

4.4.1 Marine growth data are to be site specific and are represented by:

- thickness of marine growth
- dependance of marine growth on depth below sea level.

Note 1: Nature as thickness and depth dependence is linked to the site conditions.

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