Classification and Certification of Floating Offshore Wind Turbines

January 2019

Rule Note
NI 572 DT R02 E

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BUREAU VERITAS MARINE & OFFSHORE

GENERAL CONDITIONS

1. INDEPENDENCE OF THE SOCIETY AND APPLICABLE TERMS
1.1 The Society shall remain at all times an independent contractor and neither the Society nor any of its officers, employees, servants, agents or subcontractors shall be or act as an employee, servant or agent of any other party hereto in the performance of the Services.
1.2 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.
1.3 The Society acts as a services provider. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty. The Society is not and may not be considered as an underwriter, broker in Unit's sale or chartering, expert in Unit's valuation, consulting engineer, controller, naval architect, designer, manufacturer, shipbuilder, repair or conversion yard, charterer or shipowner; none of them above listed being relieved of any of their expressed or implied obligations as a result of the interventions of the Society.
1.4 The Society only is qualified to apply and interpret its Rules.
1.5 The Client acknowledges the latest versions of the Conditions and of the applicable Rules applying to the Services' performance.
1.6 Unless an express written agreement is made between the Parties on the applicable Rules, the applicable Rules shall be the Rules applicable at the time of entering into the relevant contract for the performance of the Services.
1.7 The Services' performance is solely based on the Conditions. No other terms shall apply whether express or implied.

2. DEFINITIONS
2.1 **"Certificate(s)"** means classification or statutory certificates, attestations and reports following the Society's intervention.
2.2 **"Certification"** means the activity of certification in application of national and international regulations or standards, in particular by delegation from different governments that can result in the issuance of a Certificate.
2.3 **"Classification"** means the classification of a Unit that can result or not in the issuance of a classification Certificate with reference to the Rules. Classification is an appraisement given by the Society to the Client, at a certain date, following surveys by its surveyors on the level of compliance of the Unit to the Society's Rules or to the documents of reference for the Services provided. They 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.
2.4 **"Client"** means the Party and/or its representative requesting the Services.
2.5 **"Conditions"** means the terms and conditions set out in the present document.
2.6 **"Industry Practice"** means international maritime and/or offshore industry practices.
2.7 **"Intellectual Property"** means all patents, rights to inventions, utility models, copyright and related rights, trade marks, logos, service marks, trade dress, business and domain names, rights in trade dress or get-up, rights in goodwill or to sue for passing off, unfair competition rights, rights in designs, rights in computer software, database rights, topography rights, moral rights, rights in confidential information (including know-how and trade secrets), methods and protocols for Services, and any other intellectual property rights, in each case whether capable of registration, registered or unregistered and including all applications for and renewals, reversions or extensions of such rights, and all similar or equivalent rights or forms of protection in any part of the world.
2.8 **"Parties"** means the Society and Client together.
2.9 **"Party"** means the Society or the Client.
2.10 **"Register"** means the public electronic register of ships updated regularly by the Society.
2.11 **"Rules"** means the Society's classification rules and other documents. The Society's Rules take into account at the date of their preparation the state of currently available and proven technical minimum requirements but are 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.
2.12 **"Services"** means the services set out in clauses 2.2 and 2.3 but also other services related to Classification and Certification such as, but not limited to: ship and company safety management certification, ship and port security certification, maritime labour certification, training activities, all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board. The Services are carried out by the Society according to the applicable referential and to the Bureau Veritas' Code of Ethics. The Society shall perform the Services according to the applicable national and international standards and Industry Practice and always on the assumption that the Client is aware of such standards and Industry Practice.
2.13 **"Society"** means the classification society **'Bureau Veritas Marine & Offshore SAS'**, a company organized and existing under the laws of France, registered in Nanterre under number 821 131 844, or any other legal entity of Bureau Veritas Group as may be specified in the relevant contract, and whose main activities are Classification and Certification of ships or offshore units.
2.14 **"Unit"** means any ship or vessel or offshore unit or structure of any type or part of it or system 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.

3. SCOPE AND PERFORMANCE
3.1 Subject to the Services requested and always by reference to the Rules, the Society shall:
- review the construction arrangements of the Unit as shown on the documents provided by the Client;
- conduct the Unit surveys at the place of the Unit construction;
- class the Unit and enter the Unit's class in the Society's Register;
- survey the Unit periodically in service to note whether the requirements for the maintenance of class are met.

The Client shall inform the Society without delay of any circumstances which may cause any changes on the conducted surveys or Services.
3.2 The Society will not:
- declare the acceptance or commissioning of a Unit, nor its construction in conformity with its design, such activities remaining under the exclusive responsibility of the Unit's owner or builder;
- engage in any work relating to the design, construction, production or repair checks, neither in the operation of the Unit or the Unit's trade, neither in any advisory services, and cannot be held liable on those accounts.

4. RESERVATION CLAUSE
4.1 The Client shall always: (i) maintain the Unit in good condition after surveys; (ii) present the Unit for surveys; and (iii) inform the Society in due time of any circumstances that may affect the given appraisement of the Unit or cause to modify the scope of the Services.
4.2 Certificates are only valid if issued by the Society.
4.3 The Society has entire control over the Certificates issued and may at any time withdraw a Certificate at its entire discretion including, but not limited to, in the following situations: where the Client fails to comply in due time with instructions of the Society or where the Client fails to pay in accordance with clause 6.2 hereunder.
4.4 The Society may at times and at its sole discretion give an opinion on a design or any technical element that would 'in principle' be acceptable to the Society. This opinion shall not presume on the final issuance of any Certificate or on its content in the event of the actual issuance of a Certificate. This opinion shall only be an appraisal made by the Society which shall not be held liable for it.

5. ACCESS AND SAFETY
5.1 The Client shall give to the Society all access and information necessary for the efficient performance of the requested Services. The Client shall be 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. Any information, drawing, etc. required for the performance of the Services must be made available in due time.
5.2 The Client shall notify the Society of any relevant safety issue and shall take all necessary safety-related measures to ensure a safe work environment for the Society or any of its officers, employees, servants, agents or subcontractors and shall comply with all applicable safety regulations.

6. PAYMENT OF INVOICES
6.1 The provision of the Services by the Society, whether complete or not, involve, for the part carried out, the payment of fees thirty (30) days upon issuance of the invoice.
6.2 Without prejudice to any other rights hereunder, in case of Client's payment default, the Society shall be entitled to charge, in addition to the amount not properly paid, interests equal to twelve (12) months LIBOR plus two (2) per cent as of due date calculated on the number of days such payment is delinquent. The Society shall also have the right to withhold Certificates and other documents and/or to suspend or revoke the validity of Certificates.
6.3 In case of dispute on the invoice amount, the undisputed portion of the invoice shall be paid and an explanation on the dispute shall accompany payment so that action can be taken to solve the dispute.

7. LIABILITY
7.1 The Society bears no liability for consequential loss. For the purpose of this clause consequential loss shall include, without limitation:
- Indirect or consequential loss;
- Any loss and/or deferral of production, loss of product, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case whether direct or indirect.

The Client shall defend, release, save, indemnify, defend and hold harmless the Society from the Client's own consequential loss regardless of cause.
7.2 Except in case of wilful misconduct of the Society, death or bodily injury caused by the Society's negligence and any other liability that could not be, by law, limited, the Society's maximum liability towards the Client is limited to one hundred and fifty per-cents (150%) of the price paid by the Client to the Society for the Services having caused the damage. This limit applies to any liability of whatsoever nature and howsoever arising, including fault by the Society, breach of contract, breach of warranty, tort, strict liability, breach of statute.
7.3 All claims shall be presented to the Society in writing within three (3) months of the completion of Services' performance or (if later) the date when the events which are relied on were first discovered by the Client. Any claim not so presented as defined above shall be deemed waived and absolutely time barred.

8. INDEMNITY CLAUSE
8.1 The Client shall defend, release, save, indemnify and hold harmless the Society from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, for harm or loss to persons and/or property tangible, intangible or otherwise which may be brought against the Society, incidental to, arising out of or in connection with the performance of the Services (including for damages arising out of or in connection with opinions delivered according to clause 4.4 above) except for those claims caused solely and completely by the gross negligence of the Society, its officers, employees, servants, agents or subcontractors.

9. TERMINATION
9.1 The Parties shall have the right to terminate the Services (and the relevant contract) for convenience after giving the other Party thirty (30) days' written notice, and without prejudice to clause 6 above.
9.2 In such a case, the Classification granted to the concerned Unit and the previously issued Certificates shall remain valid until the date of effect of the termination notice issued, subject to compliance with clause 4.1 and 6 above.
9.3 In the event where, in the reasonable opinion of the Society, the Client is in breach, or is suspected to be in breach of clause 16 of the Conditions, the Society shall have the right to terminate the Services (and the relevant contracts associated) with immediate effect.

10. FORCE MAJEURE
10.1 Neither Party shall be responsible or liable for any failure to fulfil any term or provision of the Conditions if and to the extent that fulfilment has been delayed or temporarily prevented by a force majeure occurrence without the fault or negligence of the Party affected and which, by the exercise of reasonable diligence, the said Party is unable to provide against.
10.2 For the purpose of this clause, force majeure shall mean any circumstance not being within a Party's reasonable control including, but not limited to: acts of God, natural disasters, epidemics or pandemics, wars, terrorist attacks, riots, sabotages, impositions of sanctions, embargoes, nuclear, chemical or biological contaminations, laws or action taken by a government or public authority, quotas or prohibition, expropriations, destructions of the worksite, explosions, fires, accidents, any labour or trade disputes, strikes or lockouts.

11. CONFIDENTIALITY
11.1 The documents and data provided to or prepared by the Society in performing the Services, and the information made available to the Society, are treated as confidential except where the information:
- is properly and lawfully in the possession of the Society;
- is already in possession of the public or has entered the public domain, otherwise than through a breach of this obligation;
- is acquired or received independently from a third party that has the right to disseminate such information;
- is required to be disclosed under applicable law or by a governmental order, decree, regulation or rule or by a stock exchange authority (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure.

11.2 The Parties shall use the confidential information exclusively within the framework of their activity underlying these Conditions.
11.3 Confidential information shall only be provided to third parties with the prior written consent of the other Party. However, such prior consent shall not be required when the Society provides the confidential information to a subsidiary.
11.4 Without prejudice to sub-clause 11.1, the Society shall have the right to disclose the confidential information if required to do so under regulations of the International Association of Classifications Societies (IACS) or any statutory obligations.

12. INTELLECTUAL PROPERTY
12.1 Each Party exclusively owns all rights to its Intellectual Property created before or after the commencement date of the Conditions and whether or not associated with any contract between the Parties.
12.2 The Intellectual Property developed by the Society for the performance of the Services including, but not limited to drawings, calculations, and reports shall remain the exclusive property of the Society.

13. ASSIGNMENT
13.1 The contract resulting from to these Conditions cannot be assigned or transferred by any means by a Party to any third party without the prior written consent of the other Party.
13.2 The Society shall however have the right to assign or transfer by any means the said contract to a subsidiary of the Bureau Veritas Group.

14. SEVERABILITY
14.1 Invalidity of one or more provisions does not affect the remaining provisions.
14.2 Definitions herein take precedence over other definitions which may appear in other documents issued by the Society.
14.3 In case of doubt as to the interpretation of the Conditions, the English text shall prevail.

15. GOVERNING LAW AND DISPUTE RESOLUTION
15.1 These Conditions shall be construed and governed by the laws of England and Wales.
15.2 The Parties shall make every effort to settle any dispute amicably and in good faith by way of negotiation within thirty (30) days from the date of receipt by either one of the Parties of a written notice of such a dispute.
15.3 Failing that, the dispute shall finally be settled under the Rules of Arbitration of the Maritime Arbitration Chamber of Paris ("CAMP"), which rules are deemed to be incorporated by reference into this clause. The number of arbitrators shall be three (3). The place of arbitration shall be Paris (France). The Parties agree to keep the arbitration proceedings confidential.

16. PROFESSIONAL ETHICS
16.1 Each Party shall conduct all activities in compliance with all laws, statutes, rules, economic and trade sanctions (including but not limited to US sanctions and EU sanctions) and regulations applicable to such Party including but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption, copyright and trademark protection, personal data protection
(https://personaldataprotection.bureauveritas.com/privacypolicy).
Each of the Parties warrants that neither it, nor its affiliates, has made or will make, with respect to the matters provided for hereunder, any offer, payment, gift or authorization of the payment of any money directly or indirectly, to or for the use or benefit of any official or employee of the government, political party, official, or candidate.
16.2 In addition, the Client shall act consistently with the Bureau Veritas' Code of Ethics.
https://group.bureauveritas.com/group/corporate-social-responsibility

GUIDANCE NOTE NI 572

NI 572

Classification and Certification of Floating Offshore Wind Turbines

January 2019

Section 1 General

Section 2 General arrangement

Section 3 Material

Appendix 3 Structural Analysis

Appendix 4 Turbine - Mechanical components

Appendix 5 Life Cycle

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 Guidance 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).

Guidelines on mechanical components of the turbine are given in App 4.

1.1.4 In general, FOWT can be considered as unmanned structures. For manned FOWT, special considerations may apply on a case by case basis.

Note 1: In the present note, FOWT is considered unmanned when no personnel are on board in normal working condition, even if some personnel are on board for short time period (e.g. maintenance operation).

1.2 Documents

1.2.1 Recognized standards and rules

Recognized Standards are listed in Tab 1, and Society Rules are listed in Tab 2.

1.2.2 Other Standards

Technical Standards, other than those stated in Tab 1 or Tab 2, 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 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.

1.3 Floating platforms

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

- Column Stabilized Units. When the FOWT is a column stabilized unit, general guidance may be found in NR571 (see Tab 2).

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 centre, 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 (see Tab 2).
- 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 (see Tab 2.

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
- tension leg system (tendon system).

Other station keeping systems are considered on a case by case basis.

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 Unmanned unit

Unmanned unit means unit where no personnel are on board in normal working condition, even if some personnel are on board for short time period (e.g. maintenance operation).

2.2.2 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:

- rotor-nacelle assembly (RNA)
- sub-structure, including the floating structure and the transition piece
- station keeping system, including mooring system, tendons or active thrusters
- foundation.

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

2.2.3 Top-structure

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

2.2.4 Support structure

The support structure consists of the foundation, station keeping system, sub-structure and the tower.

Table 1 : Recognized Standards

Reference	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 Met-ocean 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 19902	Petroleum and natural gas industries — Fixed steel offshore structures	General requirements applicable 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	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms	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
AWS D1.1	Structural Welding Code - Steel	Welding
IMO MSC 267(85)	International Code on Intact Stability (IS Code 2008)	General requirements for stability
IMO MSC/Circ.884	Guidelines for safe ocean towing	Towing
IMO A765(8)	Guidelines on the safety of towed ships and other floating objects including installations, structures and platforms at sea	Towing
EN 1992	Eurocode 2: Design of concrete structures	Concrete structure requirements
EN 206	Concrete - Specification, performance, production and conformity	Concrete specifications

2.2.5 Sub-structure

The sub-structure is the part of the support structure which connect the station keeping system to the tower.

Note 1: The sub-structure of FOWT can be referred as a hull.

2.2.6 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.

2.2.7 Station keeping system

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

Table 2 : Society documents

Reference	Title	Main interest
NR266	Requirements for survey of materials and equipment for the classification of ships and offshore units	General requirements for survey of material and equipment
NR216	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
NR445 **(1)**	Rules for the classification of offshore units	General requirements for offshore units
NR467 **(2)**	Rules for the classification of steel ships	General requirements for steel ships
NR493	Rules for the classification of mooring systems for permanent and mobile offshore units	General requirements for mooring systems
NR494	Rules for the classification of offshore loading and offloading buoys	General requirements for buoys
NI 525	Risk based qualification of new technology - Methodological guidelines	General guidance on qualification of new technology
NR526	Rules for the classification of lifting appliances onboard ships and offshore units	General requirements for lifting appliances
NR530	Coating performance standard	General requirements for coating performance
NR546	Hull in composite materials and plywood, material approval, design principles, construction and survey	General requirements for hull in composite material
NR561	Hull in aluminium alloys, design principles, construction and survey	General requirements for hull in aluminium
NR571	Rules for the classification of column stabilized units	General requirements for column stabilized units
NR578	Rules for the classification of tension leg platform	General requirements for tension leg platforms
NI 594	Design and construction of offshore concrete structures	General guidance on concrete structure
NR595	Classification of offshore handling systems	General requirements for Offshore Handling Systems
NR600	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	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 611	Guidelines for fatigue assessment of steel ships and offshore units	General guidance for fatigue of units
NI 615	Buckling assessment of plated structures for offshore units	Strength criteria for buckling and ultimate strength of structure
NI 631	Certification scheme for Marine Renewable Energy technologies	Certification scheme
NI 638	Long term calculations	General guidance on direct hydro-structure calculations

(1) Hereafter referred to Offshore Rules
(2) Hereafter referred to Ship Rules.

2.2.8 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, such as:

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

2.2.9 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.

2.2.10 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.

2.2.11 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 conditions being afforded by the column water plane area.

2.2.12 Yaw misalignment

The yaw misalignment means the horizontal deviation of the wind turbine rotor axis from the wind direction.

Figure 1 : Floating offshore wind turbine

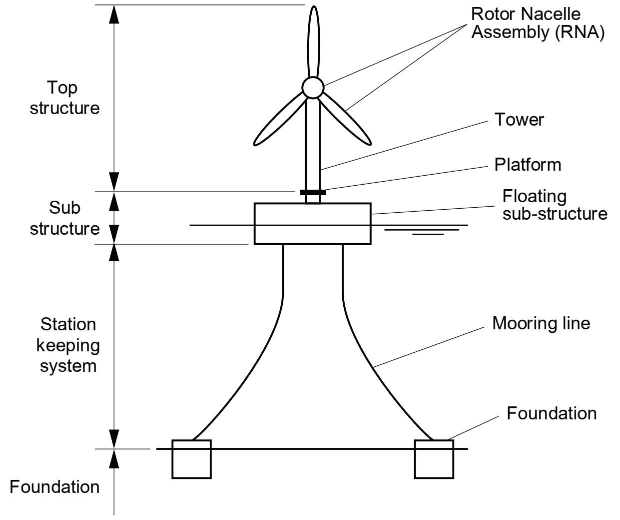
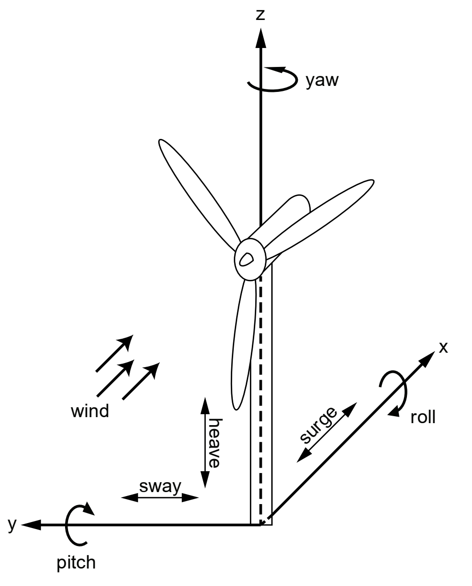


Figure 2 : Axes



3 Principles of classification and certification

3.1 Classification

3.1.1 Classification results in issuance of classification certificate attesting the level of compliance of the FOWT with the classification rules of the Society.

3.1.2 Class notation

Units complying with the requirements of this note are eligible for the assignment of the service notation **FOWT** as defined in 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:

- general arrangements drawings
- structural drawings of the floating platform and of top-structures, RNA excluded
- operating manual
- stability calculations
- details of anchoring system
- inspection, maintenance 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 5):

- 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 review of the submitted plans and documents. The 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, Met-ocean report, etc.)
- basic engineering documents, specifications of the installation
- detailed engineering documents
- 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 GENERAL ARRANGEMENT

1 Clearance / Air gap

1.1 Air gap

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

1.1.2 When wave impacts are permitted to occur on the underside of structure part it is to be demonstrated that the safety of personnel is not significantly impaired.

1.1.3 The following air gaps are to be maintained:

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

Note 1: At least, clearance is to be check for extreme conditions with return period of 50yrs.

1.1.4 Air gaps are to be checked at various points on the underside of the structure part.

1.1.5 Air gaps 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 non-linearity of wave profile
- maximum and minimum draughts
- various environmental headings.

1.2 Rotor clearance

1.2.1 At least, the lowest blade tip position is to be clear of passing wave cress under all conditions.

1.2.2 Attention is to be paid on local regulation.

Note 1: To minimize the risk of collision, it is recommended to consider a rotor clearance suitable for vessel types as identified in the traffic survey. Generally clearance between rotor and sea level at mean high water springs should be taken not less than 22 meters.

1.3 Platform clearance

1.3.1 Any walkway and platform access are to be mounted above the splash zone (as defined in Sec 4) and clearance with rotor is to be suitable to provide safe access for personnel.

2 Access means

2.1 General

2.1.1 Mean of access

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

2.1.2 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.

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

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

2.1.5 Limitation of accessibility

Accessibility of ladders and platforms is to be limited under icing conditions.

2.1.6 Means are to be provided to prevent the access of the FOWT by any unauthorized person, where appropriate.

2.2 Escape route

2.2.1 Nacelle escape

Alternative escape route from the nacelle is to be provided.

2.2.2 FOWT escape

Alternative escape route from the FOWT is to be provided in case of emergency.

2.3 Guards

2.3.1 Guards are to be designed to protect personnel from accidental contact with moving components.

2.4 Access systems - boat landing

2.4.1 Access system structure (such as fenders, boat loading, ladders) is to be designed such that the vertical movement of service ship approaching the FOWT is not restrained.

3 Access platform

3.1 Control system

3.1.1 A tagged, local, manual override on the automatic/remote control system is to be provided at the platform to allow the personnel to perform normal operation of the FOWT.

SECTION 3 MATERIAL

1 General

1.1 Application

1.1.1 This Section provides general guidance for selection of materials used on construction of FOWT.

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 (secondary application structure): structural elements of minor importance, the failure of which might induce only localized effects

  e.g. secondary beams not contributing to overall integrity, sea fastening, access system (boat landing, ladders, fenders,...), J-tube, crane resting support …
- first category (primary application structure): main load carrying elements essential to the overall structural integrity of the FOWT

  e.g. main deck beams, tubular columns, bracing members, welded beams, crane pedestal and its foundation…
- special category (special application structure): portions of the first category elements located in way or at the vicinity of critical load transmission areas and of stress concentration locations.

  e.g. major intersections of bracing members, external shell structure in way of intersections of vertical columns, decks and lower hulls, insert plate of deck plating in way of crane pedestal…

Note 1: Guidance is provided in NR426 for classification of elements into categories, according to their nature and to the structural type of unit.

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 Material strength

3.2.1 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.

4 Concrete

4.1 General

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

- EN 1992 - Design of concrete structures
- EN 206 - Concrete - Specification, performance, production and conformity
- ISO 19903 - Fixed concrete offshore structures
- NI 594 - Design and Construction of Offshore Concrete structure.

SECTION 4 CORROSION

1 General

1.1 Zone exposed to corrosive environment

1.1.1 Corrosion process is dependent on the relationship between the structure and its environment. The structure of FOWT is divided into different zones: atmospheric, splash and submerged zones, as defined hereafter.

1.1.2 Atmospheric zone

The atmospheric zone means zone which extends upwards from the splash zone (i.e. exposed to air, sun, wind, spray and/or rain).

1.1.3 Splash zone

The splash zone means zone alternatively in and out of water because of wind, wave, tide, FOWT motions, draft variation or water level change.

- For external surface, the splash zone is generally taken as extending from the deepest draught in combination with the highest still water level with a return period of 1 year increased by the crest height of a wave with height equal to the significant wave height with a return period of 1 year, to the lowest draught in combination with the lowest still water level with a return period of 1 year reduced by the trough depth of a wave with height equal to the significant wave height with a return period of 1 year.
- For internal surface, the splash zone is generally taken as extending from the lowest operational ballast water level to the highest operational ballast water level in the compartment

Note 1: The exact location and vertical extent of the splash zone is generally determined at the design stage as it depends upon environmental and operating conditions at site location.

1.1.4 Submerged zone

The submerged zone means zone permanently under water (below the splash zone).

1.2 Corrosion protection

1.2.1 Plan for the corrosion protection

An overall plan for the corrosion protection of the structure is to be prepared covering the following surfaces of the structure:

- all external surfaces (submerged, splash and atmospheric zone, boat landing, J-tube,...)
- internal surfaces (atmospheric and splash zone, ballast, storage tanks,...).

The plan for the corrosion is to take into account:

- the intended duration of operations and conditions of maintenance
- the design life (including installation life)
- the particular conditions in each zone.

1.2.2 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.

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

1.2.4 A corrosion addition is to be considered, if necessary:

- in special areas subjected to mechanical wastage due to abrasion (e.g. boat landing, access ladders)
- when the concerned structural members are left unprotected
- when the concerned structural members are not sufficiently protected against corrosion
- in areas of difficult maintenance and inspection
- in watertight compartments.

1.2.5 Corrosion protection method is to be adapted to the concerned zone (Tab 1 and Fig 1):

a) In atmospheric zone, external and internal surfaces of steel structures are to be protected by coating.

b) In splash zone, use of coating is mandatory for external surfaces of primary structures. Coating of primary structure is to be combined with a corrosion addition.

c) In submerged zone, cathodic protection is mandatory for external surfaces of steel structures. Use of coating is recommended and is then primarily intended to reduce the required cathodic protection capacity.

   Internal surfaces of the submerged zone are to be protected by either cathodic protection or corrosion addition, with or without coating in combination.

Note 1: For areas of difficult access for maintenance and inspection, and for sealed compartments, corrosion addition is recommended.

1.2.6 Mooring chains

Corrosion protection of mooring chains is to be considered as given in NR493.

1.2.7 Foundations

Corrosion protection of foundation is to be considered as given in NI 605.

Table 1 : Corrosion protection

Zone	Internal surface	External surface	Areas of difficult access or maintenance
Atmospheric	Coating	Coating	Coating + CA
Splash	Coating or CA	Coating + CA	Coating + CA
Submerged	CP or CA (+ coating recommended)	CP (+ CA **(1)** + coating recommended)	CP + CA (+ coating recommended)
Boat landing	NA	Coating (+ CA recommended)	Coating + CA
Watertight compartment	NA		CA **(2)**

For secondary structures, corrosion addition may be considered on case by case basis according to the risk of human life, the possibility of replacement and the maintenance and repair process.

CA : Corrosion addition

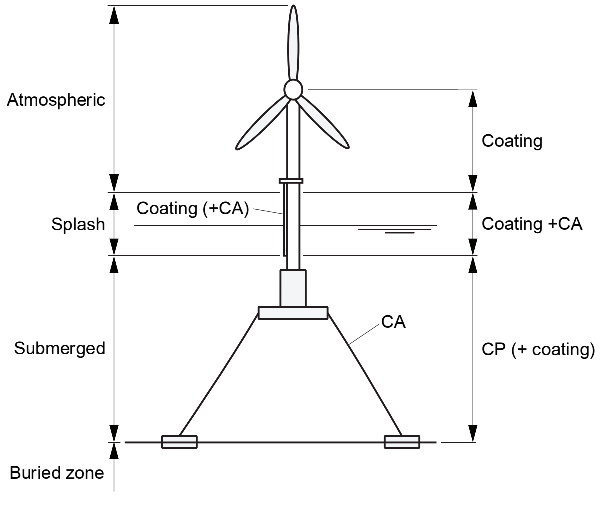
CP : Cathodic protection, i.e. sacrificial anodes system or impressed current system (impressed current system is only permitted on external surface of the structure.

NA : Not Applicable

(1) Impressed current system is to be supplemented by corrosion addition (to take into account loss of current).

(2) A corrosion addition is recommended for watertight compartments where maintenance and inspection may be difficult, and/or where loss of tightness is possible. Corrosion rate is to be specified according to the compartment volume and the oxygen level (as a guidance, a reference corrosion rate of 0,10 mm/yr may be consider).
Other methods of corrosion control such as control of humidity, control of oxygen level, overpressure (by nitrogen) to prevent air ingress, biocid, etc. may also be considered when relevant.
A corrosion addition is required for sealed compartment (no maintenance or inspection possible).

Figure 1 : Corrosion protection for external surface



1.3 Corrosion allowance

1.3.1 Net scantling approach

The scantlings obtained by applying the criteria specified in this Note are net scantlings (i.e. based on net thickness t_{net}), except when otherwise specified.

For new steel structure, the net thickness is to be taken as:

$t_{net} = t_{gross} - t_{ca}$

where:

t_{net} : net thickness, in mm

t_{gross} : gross thickness, in mm

t_{ca} : corrosion allowance, in mm
defined as a function of t_c, see [1.3.2]

t_c : corrosion addition, in mm

1.3.2 Corrosion allowance, t_{ca}

Corrosion allowance is to take into account possible thickness reductions during the expected life of the structure according to corrosion exposure.

Appropriate corrosion allowances are to be applied for computation of global stress, local stress or fatigue. The minimum recommended corrosion allowances are:

- 0.5 t_c for fatigue calculations and global FEM.
- t_c for local scantling (yielding and buckling calculations)

where t_c is the corrosion addition as defined below.

1.3.3 Corrosion addition, t_c

The values of the corrosion additions are to be applied in relation to the relevant protective coatings given in [1.2].

The Designer may define greater values of corrosion additions.

1.3.4

At a design stage, the current practise is to consider a corrosion addition according to the design life:

$t_c = c_R\, T_{expo}$

where:

t_c : corrosion addition, in mm

c_R : corrosion rate, in mm/yr

T_{expo} : exposure time, in years,

i.e. time during which the considered element is exposed to corrosive environment.

T_{expo} could consider the maintenance plan and the effectiveness of the corrosion protection.

In general: $T_{expo} = T_{DL} - T_{prot}$

where:

T_{DL} : design life of the considered element (installation time included), in years

T_{prot} : time during which the protection against corrosion is effective, in years.

Note 1: For example, T_{prot} means the design life of the coating qualified by recognized method (such as ISO 12944 or NORSOK M-501).

Note 2: When non corrosion protection is used, T_{prot} is to be taken as 0.

1.3.5 Corrosion rates, c_R

Corrosion rate is to be determined according to the site conditions and the zone exposed to the corrosive environment. It is recommended to perform in situ test measurements (ISO 11306, ISO 9226, ASTM G1). Values given in Tab 2 may be used as a general guidance only and should be adapted to the site parameters such as:

- oxygen content
- salinity
- temperature
- abrasion
- mineral fillers
- bacteria and biological activity
- hydrocarbon content
- pH.

In particular, the following site conditions may affect the corrosion rate:

- proximity with an estuary: mixed of fresh water with sea water, mineral fillers and debris
- wind induced upwelling effect
- marine growth and its maintenance
- sand entrained by wind (or rain)
- polluted area
- current, ice, condensation.

Table 2 : Corrosion rates

Zone	Climate	Corrosion rate on one side [mm/yr]	
		Internal	External
Splash	Temperate	0,10	0,30
	Mediterranean	0,15	0,35
	Tropical	0,20	0,50
Submerged		0,15	

Note 1: For mooring chains, corrosion rates are given in NR493.
Note 2: For foundations, corrosion rates are given in NI605.

2 Alternative according to classification maintenance and survey plan

2.1 General

2.1.1

When classification maintenance and survey plan, as given in NR445, Part A, is followed, the following corrosion additions may be used instead those indicated in Article [1]:

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 3 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 3, 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.

Table 3 : 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		0,50	
Moonpool		1,25	
Accommodation space		0,00	
Compartments other than 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 5 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 includes instructions regarding the safe operation of the FOWT and of the systems and equipment fitted on the unit. It 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.
- any areas where vessels are not permitted to operate in proximity to the FOWT
- maximum significant wave height for vessel operation near the FOWT

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 Transient conditions

Transient conditions correspond to temporary situation between production conditions and parked conditions, such as:

- start up
- normal shut-down
- emergency shut-down.

2.2.4 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 2.

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 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 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 2.

2.4.3 Marine conditions

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

a) 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) corresponds to the wave height conditioned to the normal wind
   - severe wave height (SWH) corresponds to the maximum wave height for which the FOWT produce electricity. The combination wind and wave has a return period of 50 years (see App 2, [3])
   - extreme wave height (EWH) corresponds to the wave height associated to extreme conditions. Return period of 50 years is generally considered App 2, [3]).

b) Current conditions

c) Tidal conditions

d) Sea ice conditions

e) Marine growth conditions.

Additional guidelines are given in App 2.

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 2.

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)
- static and installation mooring loads (e.g. pretension)
- static and installation power cable loads
- loads resulting from liquids in tanks
- variable ballast loads
- loads resulting from lifting or handling 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.

Note 1: For the purpose of local scantling, design distributed deck loads including deck self-weight are given in NR445, Pt B, Ch 2, Sec 3, Tab 1.

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 colliding loads due to accidental situation are to be considered as accidental loads, see [3.5].

Vessel impact loads are to be considered as horizontal force in frontal and side directions relative to the access system.

Note 2: Forces are not to be applied simultaneously in both direction.

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

Vessel impact loads may be assessed by different methods:

a) dynamic analysis of vessel approach considering:
   - vessel displacement and added mass
   - vessel speed according to the sea state
   - deformation properties of the vessel, fender and access system.

b) prescriptive method:

   The impact force F_{imp}, in kN/m, may be taken in relation to impact energy and spring energy:

   $$F_{imp} = \sqrt{2kE_c}$$

   where:

   k : total spring stiffness of the structure at the impact point in the impact direction, in kN/m

   Note 3: It is conservative to consider the vessel is rigid and the total energy is transferred to the structure.

   E_c : approaching vessel energy, in kJ

   Taken equal to:

   $E_c = 0,5\ (M + M_a)V^2$

   M : displacement of the approaching vessel, in tons

   M_a : added mass of the approaching vessel, in tons

   Taken equal to 0,25M

   V : specific maximum approach speed of the approaching vessel, in m/s

Note 4: Maximum approaching vessel data and its specific approach speed are usually given in the design basis.

c) when no data are available, the contact area may be designed for an impact force F_{imp}, in kN, given by:

   $F_{imp} = 2,5\ M$

   where:

   M : displacement of the approaching vessel, in tons

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 5: 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 2.

3.4.2 Environmental 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
- snow and ice loads, when relevant
- inertia loads
- dynamic mooring loads
- dynamic power cable loads.

Note 1: Reactions to environmental loads are to be considered as environmental loads

Note 2: Dynamic loads induced by unit's motions or by dynamic response to environment action are to be considered as environmental 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/m³

   Generally, ρ = 1,222 kg/m³

   S_w : Projected area of the structural element on a plane normal to the direction of the force, in m²

   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/m³

   C_D : Drag coefficient

   S : Swept area of the blades, in m²

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

Additional guidelines are given in App 2.

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 of the Offshore Rules.

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

Additional guidelines are given in App 1 and App 2.

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 centre of the floating platform, squeezing the columns toward each other. Prying is the opposite effect, when lateral load is outward away from the platform centre.

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 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 2.

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:

- breaking of mooring lines or tendons, as applicable
- accidental flooding
- hydrostatic pressure in damaged condition
- 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
- control and protection system fault
- fire and explosion
- electrical fault
- active control system fault, such as active ballast system.

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 Combination of environmental loads

For the purpose of environmental loads combination, environmental elements are to be assumed to act with different directions, unless combinations of environmental elements with same direction 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.

4.1.3 Design load cases

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.

As a guidance, the FOWT is to be designed for the following load cases as defined in [4.2] to [4.5] and sum up in Tab 2 to Tab 5.

- Load case Normal (N)
- Load case Accidental (A)
- Load case Installation, Maintenance and Repair (T)
- Load case Fatigue (F).

Other design load cases that can be more critical are also to be investigated.

4.2 Design load cases Normal (N)

4.2.1 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) transient conditions with normal wind conditions and severe wave height

c) 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.

4.2.2 Production (DLC 1.1, 1.6)

This load case includes situation of the FOWT in production condition. The FOWT is connected to the electrical network and the turbine is running.

The followings are to be taken into account:

- rotor imbalance (e.g. mass, pitch, twist)
- deviations from theoretical values, such as yaw misalignment.

Note 1: When unknown, yaw misalignment of ± 8° may be apply.

- minor faults, such as control function failure having return period less than 50 years, or normal loss of electrical network.

Note 2: Consideration should be taken on tip deflection to check minimum clearance between RNA and other part of the FOWT.

4.2.3 Transient - Start-up

This load case includes the transients from any standstill or idling situation to production.

The followings cases are to be considered:

- operating gust, considering relevant wind speeds associated to start-up (V_{in}, $V_{rated} \pm 2$ m/s and V_{out}).

  For each wind speed, the characteristic load value may be considered as the mean value of the extreme computed loads among the following operating gust timings:

  - when power production reached 50% of the maximum power
  - when power production reached 95% of the maximum power
  - 2 additional timings distributed between the above

Note 1: As an alternative, normal wind profile with extreme turbulence may be considered. The characteristic value of the load may be considered as the mean value of the extreme computed loads among at least 12 seeds.

- change in wind direction

4.2.4 Transient - Normal shut down (DLC 4.2, 4.3)

This load case includes the normal transients from any production condition to a parked condition.

The following cases are to be considered:

- operating gust

  Relevant wind speeds associated to normal shut down are to be considered ($V_{rated} \pm 2$ m/s, V_{out}, wind speeds associated to control and safety system)

  For each wind speed, the characteristic load value may be considered as the mean value of the extreme computed loads among the following operating gust timings (at least 4 azimuth positions to be considered):

  - 10 seconds before the beginning of the shut-down
  - when 50% of the initial power production level is reached
  - 4 additional timings evenly distributed between the two above.

Note 1: As an alternative, normal wind profile with extreme turbulence may be considered. The characteristic value of the load may be considered as the mean value of the extreme computed loads among at least 12 seeds.

- sea state exceeding maximum operating limits (i.e. most severe condition that triggered the safety limits of the control and protection system)

4.2.5 Transient - Emergency shut-down (DLC 5.1)

This load case includes the transients from any production condition to a parked condition due to the actuation of the emergency stop button.

The followings are to be taken into account:

- worst azimuth position of the rotor at the time of actuation of the emergency stop button
- normal sea-state conditions
- normal wind conditions considering relevant wind speeds ($V_{rated} \pm 2$ m/s, V_{out})

4.2.6 Parked (DLC 6.1, 6.3)

This load case includes situation of the FOWT in parked condition. The FOWT is either in standstill or in idling condition.

The following cases are to be considered:

- yaw misalignment of ± 8° associated with global environmental return period not less than 50 yrs
- extreme yaw misalignment of ± 20° associated with wind return period not less than 1yr.

When slippage or movement in yaw system may occur, these are to be added to the mean yaw misalignment.

Table 2 : Design load cases - Normal (N)

#	Design condition	System condition	Environmental conditions **(4)**			Element to be checked	SF
			Wind	Wave	Current		
1.1	Production	Intact	Normal **(1)**	Normal **(2)**	Normal	Rotor clearance RNA • blade root in-plane and out-plane moment • tip deflection	N
1.6		Intact	Normal turbulence)	Severe	Normal	Fully coupled analysis	N
2.1		Abnormal Minor failure of control system	Normal	Normal **(2)**	Normal	Fully coupled analysis	N
2.5		Intact Low voltage ride through	Normal	Normal **(2)**	Normal	Electrical system	N
3.2	Transient Start-up	Intact	Operating gust	Normal **(2)**	Normal	Fully coupled analysis	N
3.3		Intact	Wind direction change	Normal **(2)**	Normal	Fully coupled analysis	N
4.2	Transient Shut-down	Intact	Operating gust	Normal **(2)**	Normal	Fully coupled analysis	N
4.3		Intact Safety limits of the control and protection system triggered	Normal (Normal turbulence)	Severe	Normal	Fully coupled analysis	N
5.1	Transient Emergency stop	Intact Actuation of emergency stop button	Normal	Normal **(2)**	Normal	Fully coupled analysis	N
6.1	Parked	Intact Yaw misalignment of ± 8°	Extreme V_{e50} **(3)**	Extreme H_{s50} **(3)**	Extreme U_{50}	Fully coupled analysis	N
6.3		Intact Yaw misalignment of ± 20°	Extreme V_{e1}	Extreme H_{s1}	Extreme U_1	Fully coupled analysis	N

Note 1: Design load cases items are in general taken to be in accordance to DLC number of IEC 61400-3.

(1) Normal wind is to consider the most critical case:
- Extreme turbulence: considering blade root moments not lower than those derived from normal turbulence (extreme turbulence factor c_{et} is to be increased until extreme values are equal or higher than those computed with normal turbulence)
- Coherent gust with direction change
- Wind shear

(2) Significant wave height is taken as the expected significant wave height associated to the considered mean wind speed.

(3) Combination of wind and waves conditions associated with return period of 50 years.

(4) When no directional data are available for the specific site, the design direction is to be determined to produce the most severe effects on the FOWT.

4.3 Load cases Accidental (A)

4.3.1 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.

4.3.2 Following the HAZID & HAZOP outcomes results, the design of the FOWT is to consider the possibility of accidental loads as may result from failures of control systems, electrical network or mooring and from collisions, dropped objects, fire or explosions (see Pt B, Ch 2, Sec 1, [4.3] of the Offshore Rules).

Accidental loading cases are required for the towing/transit and site phases.

In accidental conditions, environmental loads are to be evaluated taking into account the circumstances in which the considered situation may realistically occur, and the time needed for evacuation or other remedial action.

4.3.3 Accidental loads are to be based on an FMEA or equivalent fault analysis carry out to determine relevant faults events.

4.3.4 Production (DLC 2.1, 2.3, 2.6)

This load case includes events induced by faults while the turbine is producing electricity.

The following cases are to be considered, when relevant:

- failure of control and protection system:
  - failure of rotor speed sensor
  - failure of over-speed protection
  - failure of yawing system
  - failure of pitching system
  - failure of braking system
  - erroneous activation of actuators
  - failure of active ballast control system.
  - failure of active mooring tension adjustment system
- electrical fault
  - loss of electrical network
  - fault of electrical system.

4.3.5 Parked - Loss of electrical network (6.2)

This load case includes loss of electrical network at an early stage in the storm containing extreme wind situation.

The followings are to be taken into account:

- turbulent wind
- global environmental condition with a return period not less than 50 yrs
- misalignment of wind and wave directions

Note 1: If no site data are available, misalignment within range ± 30° that results in the highest loads is to be considered.

- effect of wind direction change of up ± 180°

  (relevant when power back-up for control and safety system with a capacity of 6 hours of wind turbine operation is not provided).

Dynamic response to wind, wave and current loads is to be properly assessed, including non linear wave kinematics.

Note 2: Simulation should use turbulent inflow in combination with stochastic sea-state including at least one non linear wave of height equal to the extreme wave height.

4.3.6 Parked - Faults (7.1)

This load case includes deviations from the normal behaviour of a parked turbine.

The following faults are to be considered:

- failure of brake system
- failure of pitch system
- failure of yaw system

  yaw misalignment of ± 180° (increment not more than 10°)
- failure of active ballast control system
- failure of active mooring tension adjustment system.

The followings are to be taken into account:

- extreme wind
- global environmental conditions with return period not less than 1 year
- slippage in yaw system, if applicable
- misalignment of wind and wave directions.

Note 1: When misalignment exceed 30°, extreme wave height may be reduce due to the decay in severity of the sea state over the period associated with the change in wind direction which cause the misalignment.

Reduction of extreme wave height is to be calculated taking account of the water depth, fetch and other relevant site conditions.

4.3.7 Failure of mooring line (DLCs 9.1, 9.2, 10.1, 10.2)

This load case includes the mooring line failure events (see Sec 10). It may be omitted for non redundant station-keeping system.

The following cases are to be considered:

- one-line damaged
  - in production condition
  - in parked condition.
- transient condition between intact and redundancy check when FOWT is closed to electrical substation or other critical installation:
  - in production condition
  - in parked condition.

The followings are to be taken into account:

- severe movement
- severe yaw misalignment
- when FOWT is in production condition:

  normal turbulent wind and normal sea state
- when FOWT is in parked condition:

  extreme wind and extreme sea state with return period not less than 50 years.

Table 3 : Load cases - Accidental (A)

#	Design condition	System condition	Wind	Wave	Current	Element to be checked	SF
2.2	Production	Abnormal Failure of control system	Normal	Normal **(1)**	Normal	Fully coupled analysis	A
2.3		Abnormal Electrical fault	Operating gust	Normal **(1)**	Normal	Fully coupled analysis	A
2.6		Abnormal Failure of sea state limit protection control	Normal	Severe	Normal	Fully coupled analysis	A
9.1		Failure of mooring line - transient conditions **(6)**	Normal	Normal **(1)**	Normal	Station keeping system **(3)** Fully coupled analysis to consider effect of: • severe movement • misalignment	A
9.2		Failure of one mooring line - damaged condition **(6)**	Normal	Normal **(1)**	Normal		A
9.3		Damage stability **(2)**	Normal	Normal **(1)**	Normal	Damage stability **(4)** Fully coupled analysis to consider effect of: • severe movement • misalignment	A
6.2	Parked	Abnormal Loss of electrical network Yaw misalignment up to 180°	Extreme **(5)**	Extreme **(5)** H_{s50}	Extreme U_{50}	Fully coupled analysis	A
7.1		Abnormal Fault of control system	Extreme V_{e1}	Extreme H_{s1}	Extreme U_1	Fully coupled analysis	A
10.1		Failure of mooring line - transient condition **(6)**	Extreme	Extreme H_{s50}	Extreme	Station keeping system **(3)** Fully coupled analysis to consider effect of: • severe movement • misalignment	A
10.2		Failure of mooring line - damaged conditions **(6)**	Extreme	Extreme H_{s50}	Extreme		A
10.3		Damage stability **(2)**	Extreme	Extreme H_{s50}	Extreme	Damage stability **(4)** Fully coupled analysis to consider effect of: • severe movement • misalignment	A

Note 1: Design load cases items are in general taken to be in accordance to DLC number of IEC 61400-3
(1) Significant wave height is taken as the expected significant wave height associated to the considered mean wind speed
(2) Flooding conditions are to be considered according to damage stability requirements as given in Sec 6 and Sec 10
(3) See Sec 10
(4) See Sec 6
(5) Combination of wind and waves conditions associated with return period of 50 years.
(6) May be omitted for non-redundant station-keeping system

4.4 Load cases Transport, IMR (T)

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

4.4.2 All wind conditions, marine conditions and design situations assumed for transport, assembly on site, access, maintenance and repair of the FOWT are to be given in the design basis.

Note 1: Sufficient margins are to be considered between design values and maximum operational values (Guidance is given in ISO 29400).

For wind speed, margin of 5m/s is recommended.

4.4.3 Loads

During FOWT transportation, installation, maintenance and repair, the following loads are to be consider, when applicable:

- weight of tools and mobile equipment
- operational loads resulting from lifting appliances in operation
- mooring and fendering loads from service vessels
- vessel impact loads
- towing loads
- operational loads resulting from load-out.

Table 4 : Load cases - Transit, Installation and Maintenance

#	Design condition	System condition	Wind	Wave	Current	Element to be checked	SF
8.1	Transit, Installation and Maintenance	Intact	Specified wind **(1)**	Specified wave **(1)**	Specified current **(1)**	According to the specified case	N
8.1.a		Intact Normal impact from service vessel	Most severe conditions for operation of service vessel	Maximum wave for vessel operation	Most severe conditions for operation of service vessel	Boat landing, ladders and other secondary structure in or near the waterline	N
8.1.b		Abnormal **(3)** Collision with drifting vessel	Most severe conditions for operation of drifting vessel			Primary structure in and near the waterline	A
8.1.c		Intact Towing	Specified wind **(1)**	Specified wave **(1)**	Specified current **(1)**	Towing foundation and equipment	T
8.1.d		Intact Load-out	Specified wind **(1)**	NA	NA	Reactions imposed by load-out configuration (trailer/SPMT support reactions)	N
8.1.e		Intact Lifting	Specified wind **(1)**	-	-	Lifting/crane foundation	T
8.1.f		Intact Mooring line installation	Specified wind **(1)**	Specified wave **(1)**	Specified current **(1)**	Foundations of offshore handling systems (e.g. winches, sheaves, chain jacks, strand jacks, etc.) used for mooring lines installation	T
8.1.g		Intact Dropped object	-	-	-	Deck structure	**(4)**
8.2		Partially completed FOWT	Extreme **(2)** V_{e1}	Extreme **(2)** H_{s1}	Extreme **(2)** U_1	Partial structure	T

Note 1: Design load cases items are in general taken to be in accordance to DLC number of IEC 61400-3.

(1) Maximum environmental conditions stated for transit, installation or maintenance. For weather restricted operations, the maximum conditions should consider a sufficient margin compared to the design conditions (Guidance is given in ISO 29400):
- For wind conditions, design wind speed is to consider a margin of at least 5m/s added to the stated mean wind speed.

(2) Wind and wave conditions are to be combined such as the global extreme conditions has a combined return period of 1 year.If joint probability is unknown, the extreme 10 min wind speed with RP = 1yr is assumed to occur during the extreme sea-state with RP = 1yr.

(3) Secondary application structures can become turn off. Damaged structure after collision is to withstand the load case 8.2 in order to conduct the repair works.

(4) Reference is made to NR445, Pt B, Ch 3, Sec 9.

NA : Not applicable

4.4.4 The following IMR phases are to be considered:
- load-out
- lifting
- transit (wet or dry transit)
- assembly
- installation
- collision
- dropped object
- decommissioning.

4.4.5 Service vessel impact (DLCs 8.1.a & 8.1.b)

This load case include the situations where a vessel impact the FOWT.

The followings cases are to be considered:

- normal impact from service vessel:

  Normal impact from bow or stern approach of service vessel is to be consider. Speed of the service vessel is not to be less than 0,5m/s.

  Only vessels intended to approach the access system (boat landing) are to be considered.

Note 1: Vessels not intended to approach the FOWT need not to be taken into account.

Note 2: This load case is required for verification of access system structure, see Sec 9, [1]

- accidental colliding impact from service vessel drifted laterally:

  Accidental impact from service vessel drifted laterally is to be consider. Drifting speed of the service vessel is not to be less than 2,0 m/s.

The largest authorized service vessel is to be considered.

Note 3: This load case is required for verification of primary structure (such as floating substructure hull) and could be used to support the need of damaged stability assessment.

Reference is made to NR445, PtB, Ch3, Sec9 for the verification of the structure in case of collision.

The followings are to be taken into account:

- environmental conditions according to the most severe sea state to be considered for operation of the service vessel
- service vessel added mass
- fendering system on the service vessel may be considered.

4.4.6 Transit (DLC 8.1.c)

This load case includes the towing of the FOWT.It is required in particular for verification of towing foundation and equipment.

The followings are to be taken into account:

- maximum environmental conditions stated for transit.

Note 1: Coastal state specific requirements are to be considered when applicable.

Note 2: Guidance is given in ISO 29400, IMO MSC/Circ.884 and IMO A765(18)

4.4.7 Installation (DLC 8.2)

This load case includes the different states of the FOWT(e.g. partially completed FOWT) which may persist for longer than one week during IMR.

The followings states are to be considered when relevant:

- partially completed support structure
- floating sub-structure standing without the top-structure
- support structure standing without the RNA

  (appropriate means are to be taken to avoid critical wind speeds)
- the RNA without one or more blades
- partial or temporary mooring
- damaged structure after accidental collision waiting for repair.

Note 1: For all of these states, the electrical network is assumed not connected.

The followings are to be taken into account:

- global environmental conditions with return period not less than 1 year.

Note 2: If joint probability is unknown, the extreme 10 min wind speed with return period of 1yr is assumed to occur during the extreme sea-state with return period of 1 year.

4.5 Load case Fatigue (F)

4.5.1 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.

4.5.2 Production (DLC 1.2)

This load case includes the situations of the FOWT in production condition. The FOWT is connected to the electrical network and the turbine is running.

The followings are to be taken into account:

- atmospheric turbulence
- normal sea states associated with mean wind speed:
  - significant wave height, H_s
  - spectral peak period, T_p
  - wave direction, θ_w
  - water level.

Note 1: A single value of H_s may be considered for each relevant mean wind speed.

4.5.3 Production plus fault (DLC 2.4)

This load case includes fault events (including loss of electrical network) that cause an immediate shut-down or where the loading of a such fault condition may result in fatigue damage.

The followings are to be taken into account:

- normal sea states
- normal wind turbulence

Note 1: The manufacturer is to specify the number of occurrence and/or duration of fault events.

If no information are available on frequency/duration for the events, the followings apply:

- 10 shut-downs per year for over-speed event
- 24 hours per year of operation for events with yaw error
- 24 hours per year of operation for events with pitch error
- 20 losses of electrical network connection per year

4.5.4 Transient - Start-up (DLC 3.1)

This design load case includes the events from any standstill or idling situation to production.

The followings are to be taken into account:

- normal sea states

Note 1: The number of occurrences is to be estimated based on control system behaviour.

If no information are available on start-ups, the followings apply:

- 1000 start-up at V_{in}
- 50 start-up at V_r
- 50 start-up at maximum start-up wind speed.

4.5.5 Transient - Shut-down (DLC 4.1)

This load case includes the normal transients from any production condition to a parked condition.

The followings are to be taken into account:

- normal sea states

Note 1: The number of occurrences is to be estimated based on control system behaviour.

If no information are available on shut-downs, the followings apply:

- 1000 shut-downs at V_{in}
- 50 shut-downs at V_r
- 50 shut-downs at V_{out}

4.5.6 Parked (DLC 6.4, 7.2)

This load case includes situations of the FOWT in parked condition where duration of fluctuating loading may result in fatigue damage (e.g. resonant loading due to excitation by waves and influence of low aerodynamic damping from RNA).

The following cases are to be considered:

- intact condition
- abnormal condition (e.g. failure of yaw control)

Note 1: The expected time in parked condition is to be considered for each wind speed and sea state.

Conservatively low value of availability is to be estimated by the designer. If no information, a value of 90% of availability should be considered.

The followings are to be taken into account:

- normal sea states associated with mean wind speed:
  - significant wave height, H_s
  - spectral peak period, T_p
  - wave direction, θ_w

4.5.7 Installation (DLC8.3)

This load case includes situations of the FOWT in construction and prior to its connection to the electrical network where duration of fluctuating loading may result in fatigue damage (e.g. resonant loading due to excitation by waves and influence of low aerodynamic damping from RNA).

The followings are to be taken into account:

- Partially completed FOWT, when relevant:
  - partial support structure
  - support structure standing without RNA
  - RNA without one or more blades
- normal sea states associated with mean wind speed:
  - significant wave height, H_s
  - spectral peak period, T_p
  - wave direction, θ_w

Table 5 : Design load cases Fatigue (F)

#	Design condition	System condition	Wind	Wave
1.2	Production	Intact	Normal	Normal
2.4		Abnormal Failure of control system, electrical system or electrical network loss	Normal	Normal **(1)**
3.1	Transient Start-up	Intact	Normal	Normal **(1)**
4.1	Transient Normal shut-down	Intact	Normal	Normal
6.4	Parked	Intact	Normal	Normal
7.2		Abnormal Fault conditions	Normal	Normal
8.3	Transit, Installation and Maintenance	Partially completed FOWT	Normal	Normal

Note 1: Design load cases items are in general taken to be in accordance to DLC number of IEC 61400-3.
(1) Significant wave height is taken as the expected significant wave height associated to the relevant mean wind speed.

SECTION 6 STABILITY

1 General

1.1 Application

1.1.1 Stability and watertightness of FOWT are to comply with applicable requirements of the present Section, 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 5.

1.1.2 Intact stability

Intact stability is applicable for manned FOWT and unmanned FOWT.

1.1.3 Damaged stability

The measure of the ability of a unit to survive flooding accidents caused by collision, grounding or others accidental conditions, is called "damage stability". This stability is generally attained by installing a number of watertight compartments.

Except otherwise required by National Authorities, damage stability requirements are applicable for manned FOWT.

Damage stability is not required provided that:

- FOWT is unmanned and human life is not compromised, and
- uncontrolled pollution are avoided, and
- collisions with other neighbouring facilities are avoided.

Nevertheless, it is recommended that flooding risk analysis demonstrates an acceptable survivability level (for example: collision analysis is to demonstrate the unit remain watertight after collision with the largest authorized service vessel (see Sec 5, [4.4.5])).

1.2 Specific criteria

1.2.1 If the Interested Party specifies criteria for intact and/or damage stability, these criteria are to be taken into account in addition to the criteria in the present Section and stated in the Design Criteria Statement.

1.3 Statutory requirements

1.3.1 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.

1.3.2 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.

1.4 Operating procedures

1.4.1 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.

1.5 Documentation to be submitted

1.5.1 Documents listed in Tab 1are to be submitted to the Society.

Table 1 : Documentation to be submitted for stability

#	I/A	Document
1	A	Trim and stability booklet in intact conditions and if applicable, damaged conditions
2	I	List and locations of down-flooding points
3	A	Lightweight survey and inclining test report
4	I	Description of the watertight compartments
A: to be submitted for approval I: to be submitted for information		

2 Loading conditions

2.1 General

2.1.1 The loading conditions are to consider:

- site specific environmental conditions (wind, wave, current and green water effects, when relevant)
- quasi-static effects of RNA operating conditions (overturning moment)
- freezing of ballast water, when relevant
- ice and snow accumulation, when relevant
- subsea power cable as weights

- mooring lines as weights

  (positive effects of the restoring moment of the mooring lines may be considered:

  - effect of increasing the vertical centre of gravity
  - effect of reducing the wind heeling moment).
- failure of active ballast system (most unfavourable cases), when active ballast are provided to minimized the overturning moments.

2.2 Ice and snow

2.2.1 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/m² for horizontal exposed areas
- 70 kg/m² 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.

2.3 Wind

2.3.1 The wind force, F_{wind}, in Newton, is to consider the combination of wind loads acting on the substructure, the tower and on the rotor, calculated by the below formula.

2.3.2 The wind heeling lever, in m, ℓ_{wind}, is to be taken vertically from the centre of lateral resistance of the underwater body (or the mooring lines' fairleads barycentre if the mooring lines are considered) to the centre of pressure of areas subjected to wind loading.

2.3.3 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:

$$F_{wind} = \frac{1}{2}\rho_{air}\sum(C_s C_H S \cos\theta V_{wind}^2)$$

Where:

ρ_{air} : Air specific mass, in kg/m3. Generally, ρ_{air} = 1,222 kg/m³

C_S : Shape coefficient depending on the shape of the structural member exposed to wind, see Tab 2

C_H : Height coefficient depending on the height above sea level of the structural member exposed to wind, see Tab 3

S : Projected area of the exposed surface of the structural member in upright condition, in m²

θ : Heel angle, in deg

V_{wind} : Wind speed at the considered elevation, in m/s, see Tab 4.

Table 2 : Shape coefficient, C_S

Shape of the structural element	C_S
Spherical	0,40
Cylindrical	0,50
Large flat surface	1,00
Exposed beams and girders under deck	1,30
Small part	1,40
Isolated shapes (crane, beam...)	1,50
Clustered deckhouses or similar structures	1,10

Table 3 : Height coefficient, C_H

Height above sea level of the structural member exposed to wind, in m	C_H
0 - 15,3	1,00
15,3 - 30,5	1,10
30,5 - 46,0	1,20
46,0 - 61,0	1,30
61,0 - 76,0	1,37
76,0 - 91,5	1,43
91,5 - 106,5	1,48
106,5 - 122,0	1,52
122,0 - 137,0	1,56
137,0 - 152,5	1,60
152,5 - 167,5	1,63
167,5 - 183,0	1,67
183,0 - 198,0	1,70

Table 4 : Wind speed, V_{wind}

Wind condition	Wind speed Vwind, in m/s	
	Site conditions available	Site conditions not available
Normal	$V_{10min,\ rp\ =\ 1yr}$ or $V_{cut-out}$ whichever is the less	36,0 m/s (70 knots) or $V_{cut-out}$ whichever is the less
Extreme	$V_{10min,rp\ =\ 100\ yrs}$	51,5 m/s (100 knots)
Note 1: $V_{10min,\ rp=\ X\ yrs}$: 10 minutes mean wind speed corresponding to a X years return period $V_{cut-out}$: cut-out wind speed, in m/s		

2.3.4 Wind loads on the rotor

For determination of the overturning moment due to quasi-static wind load on the rotor, the thrust force may be calculated using the thrust coefficient C_T determined by the rotor properties, control algorithm and turbine operating conditions. The thrust force generated by wind perpendicular to the swept area of the blades may be estimated by the following equation:

$$F = \frac{1}{2}\rho_{air} C_T S_b V_{hub}^2$$

Where:

F_{thrust} : Wind drag load, in N

ρ_{air} : Mass density of air, in kg/m3

C_T : Thrust coefficient

S_b : Swept area of the blades, in m2

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

When data are not available (e.g. C_T unknown), the maximum thrust with nominal wind is to be considered.

2.4 Current

2.4.1 The current heeling force on the floating platform, Fcurrent, in Newton, is to be calculated by the following formula:

$$F_{current} = \frac{1}{2}\rho_{water}\sum C_D S \cos\theta U_{current}|U_{current}|$$

where:

Ucurrent: Projection of current velocity vector normal to S, in m/s

C_D : Drag coefficient,
when no data are available C_D is to be taken equal to 1

S : Projected area of the exposed surface of the structural member in upright condition, in m²

θ : Heel, in deg

ρ_{water} : Sea water specific mass, in kg/m3

2.4.2 The levers for the current heeling moments, $\ell_{current}$ in m, is to be taken vertically from the centre of lateral resistance of the underwater body (or the mooring lines' fairleads barycentre if the mooring lines are considered) to the centre of pressure of areas subjected to current loadings.

2.5 Sea state - Wave

2.5.1 A sea state is represented by a significant wave height, a peak spectral period and a direction. The normal wave height is assumed equal to the expected value of the significant wave height conditioned by the normal wind speed.

The extreme stochastic sea state model is to be considered for both the extreme significant wave height, H_{s50} with a recurrence period of 50 years and the extreme significant wave height, H_{s1} with a recurrence period of 1 year.

3 Stability calculations

3.1 General

3.1.1 General guidance for stability calculations are given in NR445, Pt B, Ch 1 Sec 2.

3.1.2 The stability analysis is to combine the relevant overturning moments. Stability calculations are to be performed as detailed in Tab 5.

Table 5 : Stability cases

#	Loading condition	Description	Environmental conditions		
			Wind	Current	Wave
1	Lightweight	Free floating	NA	NA	NA
2	Transit **(3)**	Free floating Transit draught	Expected during transit	Towing speed limit	Expected during transit
3.1	Installation	Free floating	Expected during transit	NA	NA
3.2		Partially installed mooring lines **(1)**			
4	Maintenance **(2)**	Moored Maintenance load	Specified limiting parameters	Specified limiting parameters	Specified limiting parameters
5.1	Operation	Maximum draught	Normal	Normal	Normal
5.2		Minimum draught	Normal	Normal	Normal
5.3		One mooring line failure	Normal	Normal	Normal
6.1	Parked	Maximum draught	Extreme	Extreme	Extreme
6.2		Minimum draught	Extreme	Extreme	Extreme
6.3		One mooring line failure	Extreme	Extreme	Extreme H_{s50}

NA: not applicable
The draught is the distance, in m, from the base line to the waterline, measured amidships.
The maximum draught is the deepest draught able to be observed during operation.
The minimum draught is the lightest draught able to be observed during operation.
(1) According to installation procedures.
(2) Required if specific loads are to be considered during maintenance (such as tools, transit containers...).
(3) In the special case of towing, the overturning moments should be calculated adequately and submitted for approval.

3.1.3 Stability constrained by mooring lines or tendon

When stability of the FOWT is provided by pretension and stiffness of mooring lines or tendons (such as tension leg systems, TLP) rather than water-plan area and moments, the stability is not governed by a metacentric approach as described in this section.

The stability analysis is to show that the system is sufficiently constrained by mooring lines and tendon legs system to avoid overturning due to the combination of wind, wave and current.

The approach given in the present section may be replaced by a stability analysis considering the restoring moment due to mooring or tendon leg system.

The damage of one mooring line or tendon is to be taken into account in the stability assessment.

Note 1: Guidance on tendon leg system is given in NR578.

3.1.4 Alternative stability criteria

Alternative stability criteria may be considered by the Society, provided an equivalent level of safety is maintained and if they are demonstrated to afford adequate positive initial stability. The following is to be considered:

- environmental conditions representing realistic winds (including gusts) and waves appropriate for loading conditions covering the various operation of the FOWT (refer to Sec 5)
- dynamic response of the unit. Analysis is to include the results of wind tunnel tests, wave tank model tests, and non-linear simulation, where appropriate. Any wind and wave spectra used are to cover sufficient frequency ranges to ensure that critical motion responses are obtained
- potential for flooding taking into account dynamic responses in a seaway
- susceptibility to capsizing considering the unit's restoration energy and the static inclination due to the mean wind speed and the maximum dynamic response
- an adequate safety margin to account for uncertainties.

Note 1: The dynamic-response-based intact stability guidance may be found in the IMO intact stability code (Res MSC.267(85)).

4 Intact stability

4.1 Intact stability criteria

4.1.1 Lightweight conditions

In lightweight conditions, the metacentric height of the unit is to be positive.

4.1.2 Transit, Installation and maintenance conditions

The intact stability criteria for transit, installation and maintenance is to be submitted for approval by the company. The criteria are to give consideration to the environmental conditions and coastal state specific requirement.

Note 1: Guidance is given in ISO 29400 and IMO MSC/circ. 884 and IMO A765(18).

4.1.3 Operation and parked conditions

The following intact stability criteria are to be verified when applying the heeling moment due to wind and current:

- Initial metacentric height GM_0 is not to be less than 0,15 m
- The freeboard is to remain positive (in still water)
- The area under the righting moment curve to the second intercept or downflooding angle, whichever is less, is not to be less than 30% in excess of the area under the heeling moment curve to the same limiting angle. The righting moment curve is to be limited to the heel angle for which the inclining moment is negative (see Fig 1 and Fig 2.

5 Damaged stability

5.1 Extent of damage

5.1.1 General

For damage stability calculation, the damage parameters are to be based on damage scenarios.

The vertical extent should be investigated taking into account the operating vessels around the unit.

The bottom damage should be investigated when relevant.

Note 1: For towing and installation, guidance is given in ISO 29400

5.1.2 Damage parameters

The number of damaged compartments should be determined depending on the sea depth. The recommended number of damaged compartments to consider is the following:

- 1 compartment in shallow water (i.e. water depth less than 100m)
- 2 compartments in deep sea.

In addition, for compartment adjacent to the sea the following damage parameters are recommended:

- vertical extent of at least 4m:
  - 2 m above the seawater level
  - 2m below the seawater level

  Where a watertight flat is located within this region, the damage is to be assumed to have occurred in both compartments above and below the watertight flat in question.
- transverse penetration of 1.5m normal to the side shell.

In addition, are assumed independently flooded, any single watertight compartment wholly or partially below the waterline containing:

- water ballast pump, or
- machinery with sea water cooling system.

5.2 Damaged stability criteria

5.2.1 Lightweight conditions

In lightweight conditions, the metacentric height of the unit is to be positive

5.2.2 Transit, Installation and maintenance conditions

The damage stability criteria for transit, installation and maintenance is to be submitted for approval by the company. The criteria are to give consideration to the environmental conditions and coastal state specific requirement.

Note 1: Guidance is given in ISO 29400.

5.2.3 Operation and parked conditions

The following criteria are to be considered to assess the stability after damage:

- Considering a heeling moment induced by environmental conditions, the final waterline is to be below the lower edge of the deck line.
- The area under the righting moment curve to the second intercept or downflooding angle, whichever is less, is not to be less than the area under the heeling moment curve to the same limiting angle. The righting moment curve is be limited to the heel angle for which the inclining moment is negative.

Figure 1 : Stability curves in operation conditions

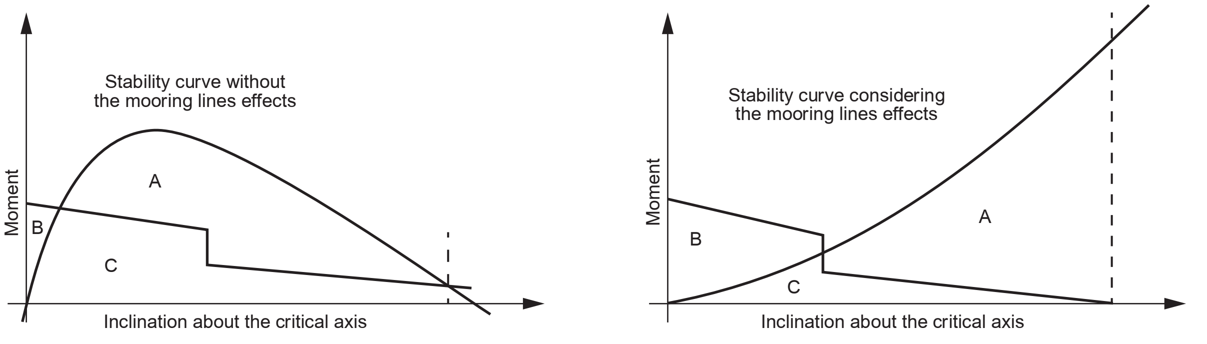
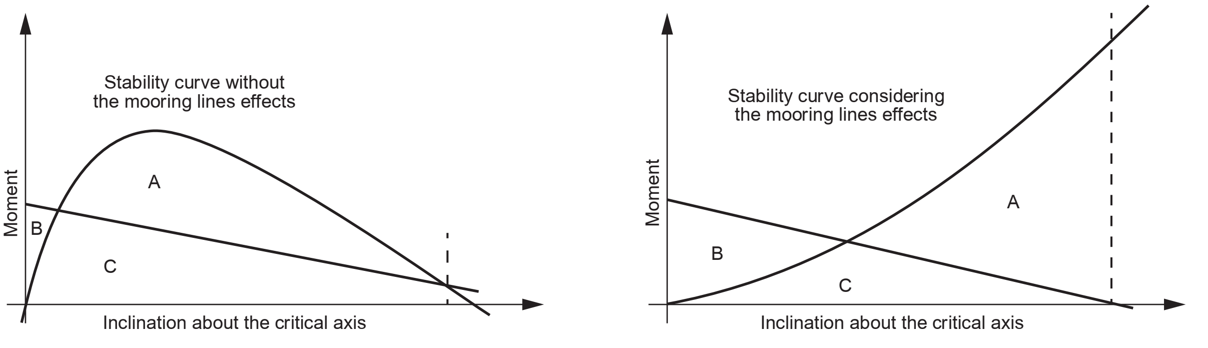


Figure 2 : Stability curves in parked conditions



SECTION 7 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 App 3.

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 10 and Sec 11).

1.1.3 Design life

Design life for structural strength and integrity assessment of FOWT hull is to be specified by the Party applying for classification/certification at the time of design and construction. The default and minimum value usually considered is 20 years.

In particular, the design life is be taken into account in the predictions of corrosion protection and fatigue strength, in conjunction with appropriate safety factors.

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 611 Guidelines for fatigue assessment of steel ships and offshore units
- 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 Recommended Practice for Planing, Designing and Constructing Fixed Offshore Platforms
- EN 1993-1 Design of steel structures.
- API RP 2T Recommended Practice for Planing, Designing and Constructing Tension Leg Platforms
- ISO 19902 Petroleum and natural gas industries - Fixed steel offshore structures

2 General structural principles

2.1 Structural continuity

2.1.1 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.

2.1.2 Snipped ends

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

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

2.1.4 Ordinary stiffeners

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

2.1.5 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].

2.1.6 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.

2.1.7 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 AWS D1.1 Structural welding Code - Steel, in its latest edition.

2.2 Small hatches

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

3 Structural strength 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 5) and/or operate under the following limit states:

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

a) For uni axial 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, in N/mm²

τ : Shear stress, in N/mm²

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 $\sigma_1 \cdot \sigma_2 < 0$:

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

c) For analyses based on finite element models, the Von Mises equivalent stress σ_c, in N/mm², at the centroid of the mid-plane layer of each element, is given by:

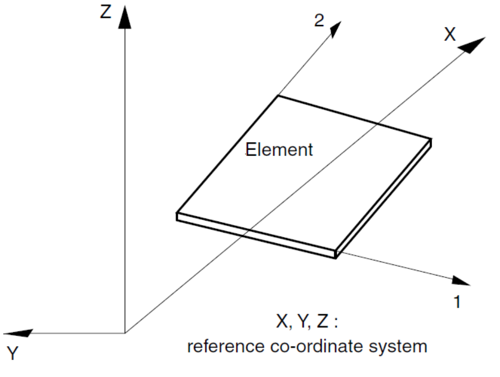
$$\sigma_c = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2 + 3\tau^2}$$

Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 1.

Where:

σ_1, σ_2 : Principal stress in the element under study, including the effect of both global and local loads, in N/mm²

Figure 1 : Reference and element co-ordinate systems



3.1.4 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 (N)	Load case (A)	Load case (T)	Load case(F)
Fixed loads	1,0	1,0	1,0	1,0
Operational loads	1,35	1,1	1,5	1,0
Environmental loads	1,35	1,1	1,5	1,0
Accidental loads	1,1	1,1	1,1	1,0
Favourable loads	0,9	0,9	0,9	1,0
(1) Partial safety factors are to be stated in the design documentation.				

Table 2 : LRFD - Material and resistance partial safety factors

<table>
<tr><th colspan="2" rowspan="3"></th><th rowspan="3">γ_m</th><th colspan="3">γ_R</th></tr>
<tr><th rowspan="2">Yielding</th><th colspan="2">Buckling</th></tr>
<tr><th>Plate panels</th><th>Pillars, struts and cross ties</th></tr>
<tr><td colspan="2">Ordinary stiffeners</td><td>1,02</td><td>1,02</td><td colspan="2">1,10</td></tr>
<tr><td colspan="2">Plating</td><td>1,02</td><td>1,20</td><td colspan="2">1,10</td></tr>
<tr><td rowspan="3">Primary supporting members</td><td>Isolated beam model</td><td rowspan="3">1,02</td><td>1,15</td><td>1.10</td><td rowspan="3">1,15</td></tr>
<tr><td>Beam or coarse mesh finite element model</td><td>1,20</td><td rowspan="2">1.02</td></tr>
<tr><td>Standard or fine mesh finite element model</td><td>1,05</td></tr>
<tr><td colspan="2">Bolted connections, fillet, partial penetration welds</td><td>1,02</td><td>1,30</td><td colspan="2">NA</td></tr>
<tr><td colspan="6">(1) Partial safety factors are to be stated in the design documentation.</td></tr>
</table>

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 App 3.

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 5.

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 3, [3.2.1]

SF : Safety factor, as given in Tab 3.

Table 3 : Safety factor SF, for yielding

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

Note 1: 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).

Load assessment may be considered with high level of confidence when loads have been established by for example: measurement or met-ocean data with low uncertainties, time domain calculation of response loads, final load iteration...

4.3 Buckling

4.3.1 General

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

4.3.2 Panels, stiffeners, primary supporting members, struts, pillars, cross ties, corrugated bulkhead

For stiffened panels, struts, pillars cross ties and corrugated bulkhead, buckling check is to be performed according to guidance note NI 615.

Note 1: The allowable utilisation factors η_{ALL} are given in [4.3.5].

4.3.3 Tubular members

The buckling of tubular members is to be checked according to recognized codes or standards (cf. [1.2.2]).

4.3.4 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.

4.3.5 Buckling check

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.

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

$$\eta \le \eta_{ALL}$$

with:

- in WSD format:

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

  With SF given in Tab 4.

- in LRFD format:

  $$\eta_{ALL} = 1/(\gamma_m \gamma_R)$$

  with γ_m and γ_R given in Tab 2.

Note 1: NI 615 is based on WSD format. Nevertheless, NI615 may be used in combination with LRFD format with the following considerations:

- applied loads are to consider partial safety factors γ_i for loads as given in Tab 1
- do not use γ_m nor γ_R in formulae of NI 615.

Table 4 : Safety factor SF, for buckling

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

Note 1: 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).

Load assessment may be considered with high level of confidence when loads have been established by for example: measurement or met-ocean data with low uncertainties, time domain calculation of response loads, final load iteration...

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 guidance note NI 611 considering corrosion allowances, loading conditions, load cases and acceptance criteria as specified in the present note. Other recognized methods may be accepted upon the acceptance of the Society.

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 are to be duly documented to the satisfaction of the Society (see also App 3, [4.3])

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

5.1.7 Corrosion

Effects of corrosive environment on fatigue life are to be taken into by means of:

- thickness decrease (i.e. consideration of corrosion allowance, t_{ca})
- fatigue strength decrease (modification of S-N curves)

a) When the structure is in non-corrosive environment or protected against corrosive environment during whole fatigue life, the design fatigue life is represented by a single period of condition which consider:

- S-N curves according to the environmental condition and corrosion protective mean
- no corrosion allowance (t_{ca} = 0).

b) When the structure is subjected to different corrosion exposure periods, the design fatigue life is represented by one period of protection and a second period of no protection against corrosion:

- During protected period:

  same consideration as item a) above.

- During exposed period:

  S-N curve under free corrosion

  corrosion allowance taken as the corrosion addition (t_{ca} = t_c), t_c as calculated in Sec 4.

Note 1: This situation corresponds for example to coated structure without coating maintenance.

c) When the structure is not protected against corrosive environment, the design fatigue life is represented by a single period of exposure to corrosion which consider:

- S-N curve under free corrosion
- corrosion allowance taken as the half of the corrosion addition, (t_{ca} = 0,5t_c), t_c as calculated in Sec 4.

5.2 Fatigue check

5.2.1 Acceptance criteria

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

5.2.2 Fatigue factors, FF

The fatigue factors (FF) applicable to the elements are be chosen according to the consequence of failure of these elements and the accessibility for inspection, maintenance and repair.

a) Unmanned unit:

For unmanned FOWT, all primary members and watertight external boundaries are to be considered as crucial unless dully justified by an analysis of the consequence of failure.

b) Manned unit:

For manned FOWT, all primary members and watertight external boundaries are to be considered as critical unless duly justified by an analysis of the consequence of failure.

Table 5 : Fatigue factors, FF

Consequence of failure	Degree of accessibility for inspection, maintenance and repair		
	Not accessible **(3)**	Underwater inspection **(4)**	Dry inspection
Critical **(1)**	0,1	0,25	0,5
Crucial **(2)**	0,2	0,4	0,6
Non-critical	0,3	0,6	1,0

(1) Critical damage include loss of life, uncontrolled pollution and unacceptable consequence (e.g. critical production losses)
(2) Crucial damage include collision, other major damage to the FOWT and major production losses.
(3) Includes areas that can be inspected in dry or underwater conditions but require heavy works for repair.
(4) Includes areas that can be inspected in dry conditions but with extensive preparation and heavy impact on operation.
Note 1: Fatigue factors given in Tab 5 are based on inspection plan considering inspections at intervals not less than 5 years. Elements which are designed to be inspection free are to be considered as not accessible elements.

6 Serviceability limit state (SLS)

6.1 General

6.1.1 The serviceability limit state concerns the normal use of the FOWT. It may include for example:

- 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 for deck beams, δ_{max}, is to satisfy the following criteria:

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

where:

L : Span of the beam, in m.

SECTION 8 HULL SCANTLINGS

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 7 and App 3.

1.1.2 The structural analysis is to consider all relevant load cases, with design conditions and corresponding loads as defined in Sec 5.

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 5 and the associated safety factors defined in Sec 7.

1.2.2 The scantlings obtained by applying the criteria given in Sec 7 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 4.

1.2.3 Plating

Scantling of hull plating is to be assessed against yielding and buckling with criteria stated in Sec 7.

1.2.4 Ordinary stiffeners

Scantling of ordinary stiffeners is to be assessed against yielding and buckling with criteria stated in Sec 7.

1.2.5 Primary supporting members

Scantling of primary supporting members is to be assessed against yielding and buckling with criteria stated in Sec 7.

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 9 OTHER STRUCTURES

1 Access system structure

1.1

1.1.1 The access system is to be designed against normal impact loads from service vessel approaching the FOWT.

Secondary application structure (boat landing, fenders, ladders,...) are be designed to withstand normal impact of service vessel without damage to such an extent that they lose their respective function as access structures.

1.1.2 Secondary application structure are to withstand 0,5 of the operational impact load applied vertically for both upward and downward direction.

2 Supporting structure of mooring system

2.1 Turret mooring system

2.1.1 For supporting structure of turret mooring system, reference is made to NR445, Pt D, Ch 1, Sec 8.

2.2 Spread mooring system

2.2.1 For spread mooring system, reference is made to NR445, Pt D, Ch 1, Sec 8.

3 Supports for hull attachments and appurtenances

3.1 General

3.1.1 For structure supporting the attachments and appurtenance, reference is made to NR445, Pt D, Ch 1, Sec8 considering conditions given in Sec 5 and associated safety factors given in Sec 7.

3.2 Lifting appliances foundations

3.2.1 For lifting appliances foundations, reference is made to NR467, Pt E, Ch 8, Sec 4 considering selection of steel grade as given in Sec 3.

4 Helicopter deck

4.1 General

4.1.1 For helicopter deck, reference is made to NR445, Pt B, Ch 3, Sec 4.

5 Hull outfit

5.1 Bulwarks and guard rails

5.1.1 For bulwarks and guard rails, reference is made to NR467, Pt B, Ch 9, Sec 2.

5.1.2 The perimeter of all open deck areas, walkways around accommodation spaces, catwalks and openings are also to be protected with similar guards.

Note 1: In case of large bulwarks, a direct calculation may be requested.

5.2 Towing foundations

5.2.1 For the evaluation of loads applied to fairleads, winches and other towing, mooring and anchoring equipment, the line is to be considered as loaded to its guaranteed breaking strength.

SECTION 10 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 Mooring lines systems are in general terms, the station keeping systems of any free-floating body by means of a principally passive system.

1.2.2 The design of the mooring system is to be in accordance with the requirements of NR493. Deviations applicable to a FOWT are described in Article [2].

1.3 Tendon Legs Systems

1.3.1 Tendon legs systems are in general terms the station keeping systems of any restrained floating body by means of tendons.

Note 1: Station keeping system of restrained floating body by means of a mix of tendons and mooring chains can be likened to a tendon legs system after consideration by the Society on a case by case basis.

1.3.2 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 Article [3].

1.4 Dynamic positioning systems

1.4.1 Dynamic positioning systems are in general terms, the station keeping systems of free-floating body by means of an active system which automatically maintains its position and/or heading (fixed location, relative location or predetermined track) by means of thruster force.

2 Design of Mooring lines

2.1 General

2.1.1 This Article deals with the different types of anchoring patterns (such as spread mooring, internal or external turret, etc.), line make up, and the associated materials (such as chain, wires, fibre ropes, etc.) in catenary or taut configuration.

2.2 Methods of evaluation

2.2.1 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.

2.3 Design conditions

2.3.1 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 met-ocean parameters and configurations of the system.

2.3.2 Configurations of the system

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

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 analyse 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 [2.8.1].

Note 1: Non-redundant station keeping system means station keeping system which does not fulfill requirements in damaged condition.

2.4 Environment and actions

2.4.1 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 5 and App 2.

2.4.2 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.

2.4.3 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.

2.5 Design Tensions

2.5.1 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.

2.5.2 Design tensions

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

2.6 Design Offsets

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

2.6.2 Methods for design offsets calculations are presented in NR493.

2.7 Fatigue analysis

2.7.1 General

For fatigue analysis, a series of met-ocean 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.

2.7.2 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.

2.8 Criteria

2.8.1 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 [2.5].

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.

2.8.2 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.

2.8.3 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 elastomer 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 behaviour. 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 5.

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

Note 1: For station keeping system of restrained floating body by means of a mix of tendons and mooring chains, mooring system is to remain taught.

Possible twist and excessive wear in mooring chains are to be avoided. Tension in mooring chains is to remain positive.

3.3.3 Environmental conditions

Environmental conditions and loads to consider are detailed in Sec 5.

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.

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 fibre 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.

SECTION 11 SOIL AND 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 centre 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 Article [2].

General requirements are given in NI 605, Sec 3.

SECTION 12 MARINE SYSTEMS

1 General

1.1 Application

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

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.

Portable means of pumping may be acceptable for unmanned FOWT in lieu of a fixed bilge system.

2.1.3 Void compartment

Void compartments are to be provided with suitable means of access.

Automatic means are to be provided to detect the presence of water in void compartments through which pipes conveying liquid pass. In the event of water detection, an alarm is to be given in a manned control room.

Note 1: When located onshore, the control room is also included in the scope of classification

Void compartments adjacent to the sea and void compartments through which pipes conveying liquids pass are to fitted with separate sounding pipes or means to determine the liquid level.

2.1.4 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 at least two pumps connected to a bilge main line arranged as to allow the draining of all spaces mentioned in [2.1].

2.2.2 Where portable means of pumping are permitted, at least two pumps are to be readily available onboard the FOWT or carried by the attending service vessel, during all operations.

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

2.2.4 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 General

3.1.1 Each FOWT is to be provided with a ballast system capable of adjusting the trim and the draught at any time, in particular when required for stability purposes.

The ballast system is to provide the capability to ballast and deballast all ballast tanks that are not used as permanent ballast tanks.

3.1.2 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.

4 Electrical installations

4.1 General

4.1.1 Electrical installation of the FOWT are to be in accordance with Society rules or IEC publications, notably the IEC 60092 series, IEC61892 series.

Note 1: For FOWT, IEC 61400 series require that electrical system of the support structure shall be in accordance to IEC or Classification Society rules.

4.2 Offshore structure marking

4.2.1 Marking lights and sound signals are to be fitted on offshore structures, following IALA recommendations and national authorities regulations.

4.3 Lightning and earth protection

4.3.1 Lightning strikes of offshore wind turbines may be more frequent and more severe than onshore. The provisions for lightning protection required in IEC 61400-24 may be considered as adequate for offshore wind turbines.

4.3.2 For metallic hull, the earthing system requirements are considered fulfilled and no additional measures such as ring electrode, etc. are required. Interconnection of substructure other than by the connection of power collection system cable shields to local earth at both ends is generally not required.

External earthing systems of copper cannot be used off shore due to corrosion issues.

4.3.3 A protective system is to be fitted to hull of non-metallic construction or having a substantial number of non-metallic members. The lightning and earthing system is to be designed in accordance with the requirements of IEC 61892-6 and IEC60092-401.

4.3.4 Earth conductors

The cross section of the earth conductors is to be at least 70mm².

4.3.5 Earth electrode

The dimensions of the earth electrode is to be compliant with IEC60092-401.

Electrode is to be permanently immersed.

4.3.6 Corrosion prevention

Precautions are to be taken to prevent corrosion with other immersed metallic fittings such as the bottom earthing wire.

4.3.7 Protection in dry dock

Suitable means are to be provided to enable the connection of the lightning protection to an efficient earth when in dry dock.

APPENDIX 1 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/m³
- 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/s².

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 non-linear character of Morison formula, proper linearisation 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 Hubble 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 Hubble **(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 2 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 Article [2]
- for waves conditions, in Article [3]
- for other marine conditions, in Article [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 also required according to IEC 61400-3.

1.2.4 Met-ocean database

The met-ocean 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 met-ocean parameters.

Met-ocean 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 met-ocean 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 ≤ 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 Wind values

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

- annual average wind speed at hub height, V_{ave}
- extreme wind speed at hub height with recurrence period of 50 years, V_{e50}
- extreme wind speed at hub height with recurrence period of 1 year, V_{e1}
- wind speed probability density function
- wind speed distribution (Weibull, Rayleigh, measure,...)
- ambient turbulence standard deviation
- turbulence intensity as a function of mean wind speed (for normal and extreme wind model)
- wind shear
- air density
- average inclined flow
- 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 met-ocean 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, turbulence intensity and conversion factors between 10-min average wind speed and given average wind speed are given in Tab 1.

Note 1: These conversion factors are applicable for wind models recommended by this note. When other wind model is used, other conversion factors may be required.

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.

Table 1 : Wind conversion factors

Averaging period	Speed correction factor	Turbulence
10 minutes	1,00	σ_{10min}
1 hour	0,95	σ_{10min} + 0,2m/s
3 hours	0,90	case by case

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:

$$\sigma_1 = \frac{V_{hub}}{\ln\left(\frac{z_{hub}}{z_0}\right)} + 5,12 \times I_{15}$$

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) 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:

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

where:

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

c_{et} : Factor for extreme turbulence, taken equal to 2m/s or higher

c) 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:

$$V_{gust} = Min\left\{\begin{matrix} 1,35V_{3s,1} - V_{hub} \\ 0,9LnT_g + 1,18 \cdot \dfrac{\sigma_1}{1 + 0,1\dfrac{D}{\Lambda_1}} \end{matrix}\right\}$$

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:

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

Note 2: Systems period can be disregarded if they are less than 7s.

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

Note 3: Resonance and interaction of gust with the FOWT is possible.

d) 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.

e) Coherent gust with direction change

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

$V_{cg} = 15$ m/s

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

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.

f) Wind shear

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

When no site-specific data are available, the transient vertical wind shear and transient horizontal wind shear may be 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:

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

Table 2 : Wind conditions

Wind model	V_{hub}	Wind profile	
Normal	$V_{hub} \in [V_{in} ; V_{out}]$	$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0,14}$	$\sigma_1 = \frac{V_{hub}}{\ln\left(\frac{z_{hub}}{z_0}\right)} + 5,12 \times I_{15}$
		z_0 : Roughness length, in m	
Extreme turbulence	$V_{hub} \in [V_{in} ; V_{out}]$	**(1)**	$\sigma_{1,et} = c_{et} I_{15}\left(0,072\left(\frac{V_{ave}}{c_{et}} + 3\right)\left(\frac{V_{hub}}{c_{et}} - 4\right) + 10\right)$
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)** $V(z,t) = V(z) - 0,37 V_{gust} \sin\left(\frac{3\pi}{T_g}t\right)\left(1 - \cos\left(\frac{2\pi}{T_g}t\right)\right)$	$V_{gust} = \text{Min}\left\{ \begin{matrix} 1,35 V_{3s,1} - V_{hub} \\ 0,9 \,\text{Ln} T_g + 1,18 \cdot \frac{\sigma_1}{1 + 0,1\frac{D}{\Lambda_1}} \end{matrix} \right\}$
		$V_{3s,1}$: 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	
Extreme	$V_{hub,1}$ $V_{hub,50}$	$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0,11}$	$\sigma_{1,e} = 0,11V_{hub}$

(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 1.

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:

$H_{50} = 1,86 H_{s50}$ and $H_1 = 1,86 H_{s1}$

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 met-ocean 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:

$U_w(0) = 0{,}01V_{1hour}(10)$

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.

APPENDIX 3 STRUCTURAL ANALYSIS

1 General

1.1 Application

1.1.1 This appendix 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 7, [3.1.1]) are analysed considering the following analysis:

- Strength analysis (see Article [3]
- Fatigue analysis (see Article [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 7, [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 7.

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]
- s tress calculations, see [3.4].

3.2 Loads and loads effects calculations

3.2.1 General

Based on load cases defined in Sec 5, [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 behaviour of both the top-structure and the sub-structure (including non linear behaviour)
- 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 1.

3.2.6 Mooring model

The mooring model provides mooring tensions (vertical and horizontal) at mooring points for each time step (see Sec 10).

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 7, [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 5.

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: 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 cycles, 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 term 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 cycles 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 7, [5].

APPENDIX 4 TURBINE - MECHANICAL COMPONENTS

1 General

1.1 Application

1.1.1 This appendix applies to offshore horizontal up-wind and down-wind offshore turbines when the action of hydrodynamic and aerodynamic effects and subsequent loads are transmitted to the rotating machinery and its controlling mechanisms.

Note 1: Attention is to be drawn to the fact that the loadings on drivetrains on floating wind turbines are very different from those found onshore.

1.1.2 This appendix is intended to contribute to the safe and efficient operation and maintenance plans setting the framework for the design approval of the RNA, and is prescriptive to the design, manufacture, installation of an offshore wind turbine and the associated quality management process.

1.1.3 It is not the intention of this appendix to replace education, experience, engineering or technical judgments apportioned to the designer, and thence, cannot address all aspects of the activities comprising the design, fabrication, installation, commissioning and decommissioning of floating wind turbines. Consequently, any subject not specifically addressed herein, is to not be considered banned.

1.2 Definitions

1.2.1 RNA

The term RNA refers to the rotor and blades, including the intermediate shaft sections, transmission gears, the electric generator, the shaft couplings, yawing mechanisms including drivers, brakes and power supply thereto.

1.3 Documentation required

1.3.1 The designer is to submit a general arrangement of the machine within the nacelle including a section view of the complete generator drive train from the propeller inclusive, all the way to the driven electric machine inclusive, along with a full detail description of the design philosophy of:

- Rotor & Blades

  information of design and manufacturing process along with QA/QC program and Records will be required, including but not limited to:
  - blade construction and QA/QC of its fabrication
  - methods for fastening the blade to the hub
  - hub design including details for non rigid hubs when applicable
  - rotor shaft along with materials and scantlings
  - rotor shaft brake
  - pitch control System
  - power Electronics, electric controls and conditions monitoring system.

Note 1: A condition monitoring system consists of sensors and data acquisition systems that collect vibration, noise, temperature and strain measurements or oil particle data during a specific period, either online with an integrated measuring system or offline with portable instruments, on a regular basis. Most of the available wind turbine condition monitoring systems is based on existing techniques from other rotating machine industries.

- Gearbox

  The designer is to submit a detailed description of the interfaces between the gearbox and the wind turbine, including loads, motions and processes being transferred across these interfaces and a summary of the load calculations for these.
  - main shaft bearings
  - planet carrier bearings
  - planet bearings
  - intermediate shaft bearings
  - high speed shaft bearings.
- Yaw System
  - Operational philosophy
  - Drawings showing components and general arrangement with details of:
    - yaw drives
    - yaw bearings
    - yaw brakes
    - motors
    - gears
    - brake ring
    - tower flange
    - Bed plate.
- Generator

  Technical Specifications and data sheet will be required

1.4 Method

1.4.1 Verification of the adequacy of the design is to be made by calculation and/or by testing. If test results are used in the verification, the environmental conditions during the test are to reflect the real characteristics and behaviour of the floating unit as a whole and under production at grid different loads.

1.4.2 The designer is to demonstrate having a suitable Quality Assurance and Quality Control program in compliance with all applicable and recognized standards. This program is to be an integral part of the design, procurement, manufacture, installation, operation and maintenance of the product as a whole.

1.5 Failure Mode and Effect Analysis

1.5.1 A complete FMEA is to identify throughout the service life of the offshore wind turbine potential failures by combining design, material selection and good O&M strategies and lifetime including: Life Extension, Repowering and Decommissioning

1.5.2 The FMEA should be logically and systematically structured for the detection of failures, system maintenance planning, and categorization of actions duly identified for assessing the probability of occurrence for each failure and its consequences or their criticality.

1.5.3 The FMEA should cover all relevant components and subsystems of the machine in a suitable hierarchy order and the most appropriate mitigation plan as applicable for the specific machine including:

- Blades
  - cracks
  - delamination of the composite
  - surface wear
  - increased surface roughness
  - fatigue.
- Rotor hub
  - aerodynamic asymmetry
  - yaw misalignment
  - creep and corrosion fatigue
  - non-uniform air gap (bearings)
  - shaft misalignment
  - torsional oscillation
  - deviation in the torque-speed ratio
  - mass imbalance.
- Pitch Control
  - premature brake activation
  - inability of excessive operational load mitigation
  - operation instability due to hydraulic system failure
  - air contamination in the hydraulic system
  - inability of aerodynamic braking
  - leakage in the hydraulic system
  - asymmetry in pitch angle
  - lightning strikes
  - high vibrations
  - flapwise fatigue damage
  - unsteady blades air loads
  - blade fracture
  - unsteady performance
  - corrosion.
- Gear Box
  - gear tooth damage
  - pitting
  - cracking
  - gear eccentricity
  - tooth crack
  - shaft-Gearbox coupling failure
  - scratching (abrasive wear)
  - scoring (adhesive wear)
  - lubricant viscosity changes
  - lubricant loss of water content
  - presence of additives/debris in the lubricant
  - skidding.
- Power Electronics and Electrical Controls
  - semiconductor devices defects
  - open circuit failure in 3-phase power converter
  - short circuit failure in 3-phase power converter
  - gate-drive circuit failure in 3-phase power converter
  - overheating
  - error in wind speed/direction measurement.
- Generator
  - internal short circuit
  - opening or shorting of stator or rotor winding circuits
  - dynamic eccentricity
  - rotor eccentricity
  - torque reduction
  - excessive stresses during operation
  - static and/or dynamic air gap eccentricities
  - increased torque pulsation
  - excessive heating in the winding
  - increase in losses and efficiency reduction
  - rotor misalignment
  - imbalances and harmonics in the air gap flux.

2 Load effects on mechanical components

2.1 General

2.1.1 The reliability of an offshore wind turbine will very much depend on the response of the supporting structure and its tolerability to specific environmental conditions, which are representative of the offshore wind turbine site and may include but not being limited to:

- marine conditions also referred hereinafter as external conditions.
- dynamic loads including hydrodynamic and aerodynamic loads.
- consequential effects including gyroscopic, yaw and strains induced in materials and the interaction between components.

2.1.2 Attention should be paid to the behaviour of the tower when the latter may imbalance and/or change the vibration dampening of the rotating parts of the machine by:

- fatigue
- cracks
- excessive fouling of foundation
- soil instability
- earthquakes
- corrosion
- loss of capacity in foundation due to cyclic loading.

2.1.3 The designer is responsible to determine the load effects for all relevant combinations of the environment and characteristics of the floating unit that may impact its mechanical components; such as the RNA, which may have been designed initially on the basis of a standard wind turbine to be installed onshore. The gap existing between the latter and the floating design will be evaluated by the Society; whereas in that case the designer is to demonstrate that the offshore site specific external conditions do not compromise the structural integrity of the machine, taking account the reserve margins and the influence of the environment on structural resistance and the appropriate material selection.

2.1.4 The calculation of loads and deflections is to also take account of the influence of site particulars for estimating the lifetime of the offshore wind turbine, as well as potential long term time variation of these dynamic properties due to seabed movement and scour when applicable.

2.1.5 For each of the defined interfaces, information is to be provided for describing the pertinent operating conditions and reactions including their dynamic excitations due to:

- forces
- moments
- rotational speeds
- motions
- offsets
- misalignments
- deflections
- accelerations
- temperatures-nominal, maximum and minimum.

2.2 Dynamic loads

2.2.1 The design is to take into account the representative values or limits of the variable conditions of the particular marine environment, specific arrangement of the machine and its suitability, considering that:

a) choice of platform or floating mode and arrangement may have direct impact on the design and behaviour of the interacting components of the machine.

b) probability of simultaneous occurrence of climatic conditions is to be taken into account when the design values are selected, including but not being limited to:
   - weight of the machine
   - tower top motion
   - controls complexity
   - maximum healing angle
   - gyroscopic effects and:
     - yawing, yaw drives, bearings & brakes
     - accelerations and decelerations
     - slip
     - torque and braking moments.

2.2.2 Dynamics loads inducing vibrations

The dynamic loads acting on the support structure that can affect the RNA as a consequence of vibration of the support structure should be duly supported by the Original Equipment Manufacture of the mayor components comprising the generator train.

Note 1: The designer may exclude the influence of the before said in 12.1 if the effect can be demonstrated to be negligible. Nevertheless, the structural integrity is to be demonstrated taking proper account of the marine conditions at each offshore wind turbine site.

2.2.3 Actuation loads

Actuation loads resulting from the operation and control of wind turbines are divided in several categories including torque control from yaw, pitch actuator loads and mechanical braking loads. In particular, for mechanical brakes, the range of friction, spring force or pressure as influenced by temperature and ageing is to be taken into account in checking the response and the loading during any braking event.

2.2.4 Aerodynamic loads

Aerodynamic loads whether being static or dynamic, are related to the airflow and its interaction with the stationary and moving parts of wind turbines, depending upon the average wind speed and turbulence across the rotor plane, the rotational speed of the rotor, the density of the air, and the aerodynamic shapes of the wind turbine components and their interactive effects, including aero elastic effects.

2.2.5 Hydrodynamic loads

The calculation of the hydrodynamic loads acting on the support structure that can affect the good performance of the machine should be performed using appropriate methods taking into account the design principle and operation philosophy of the wind turbine.

a) Sea state effect:

   The significant wave height, peak spectral period, wave direction and water level for each normal sea state (in shallow waters) are to be considered together with the associated mean wind speed, based on the long term joint probability distribution of met-ocean parameters.

b) Marine growth effect:

   The effect of marine growth on the buoyancy behaviour of the supporting structure should be taken into account. If the marine growth thickness is such that certain assemblies of components are completely blocked, the effect should be properly incorporated in the modelling of the hydrodynamic loads when these can affect the response to yaw and pitch control of blades.

2.2.6 Other loads

Other loads such as wake loads, impact loads, ice accumulation loads, etc., may occur and are to be included where the response of a floating offshore wind turbine can change due to the angle of inclination.

The effects of change of gyro-moment and the motion imposed to the machine at the angle of inclination, response of each motion, heave, pitch, and yaw motion is to be obtained and compared with the results of numerical computation.

Where relevant, earthquake loads are to be considered for units of the gravity-based anchor type, including hydrodynamic loads from waves resulting from sub-sea earthquakes (tsunamis) may need to be considered.

Hydrostatic loads acting on the support structure because of internal and external pressures and resulting buoyancy are to be taken into account where appropriate.

3 Design load cases

3.1 General

3.1.1 All relevant load cases with a reasonable probability of occurrence should be considered, together with the behaviour of the control and protection system.

For design purposes, the life of an offshore wind turbine is to be represented by a set of design situations covering the most significant conditions that the machine may experience throughout its life time.

3.1.2 The design load cases that may impact the machine should be good enough to be used for verifying its suitability with regards to:

a) Normal situations and extreme environmental conditions, including transportation, installation and maintenance.

b) If correlation exists between an extreme environmental condition and a fault situation, a realistic combination of the two should be considered as a design load case.

c) If the machine controller could cause the system to shut-down prior to reaching maximum yaw angle and/or wind speed, then it must be shown that the turbine can reliably shut-down under turbulent conditions with the same deterministic wind condition change.

d) For all design load cases, transient changes in mean wind direction should take into consideration the non-co-directionality of the wind and waves that may affect the behaviour of the machine. The multi-directionality of the wind and waves may, in some cases, have an important influence on the loads acting on the yawing, pitching and rolling of the entire unit.

3.1.3 In cases when, the local strains or stresses for critical locations in a given wind turbine component are governed by simultaneous multi-axial loading, other perturbations that may affect the machine are to be taken into account when deemed necessary, such as:

- wind field perturbations due to the wind turbine itself such as wake induced velocities, tower shadow, etc
- the influence of three dimensional flows on the blade aerodynamic characteristics (e.g. three dimensional stall and aerodynamic tip loss)
- unsteady aerodynamic effects structural dynamics and the coupling of vibrational modes
- aero elastic effects
- the behaviour of the control and protection system of the wind turbine
- the influence of icing of the blades or other parts of an offshore wind turbine on its aerodynamic and dynamic characteristics
- the static and dynamic properties of the interaction of the foundation and seabed
- the non-linearity of the interaction of the foundation and seabed, and the uncertainty and potential long term time variation of the dynamic properties due to scour, sand waves, etc
- the robustness of the design of an offshore wind turbine to changes in the resonant frequencies of the support structure and to changes in the foundation loading are to be assessed
- the mass of the accumulated marine growth on the resonant frequencies and dynamic loading of the support structure
- the dynamic response of the wind turbine to the combination of aerodynamic and hydrodynamic loads.

3.1.4 When the loading of the wind turbine is significantly influenced by the marine environment and the specificity of the control and regulation systems, the impacts of control actions on loads should be taken into account in the analysis so to proof the adopted criterion and suitability of the mechanical systems taking into consideration:

- the drivetrain configuration
- the selection of the rotor design
- the torque and power limiting methodology
- the control system
- forces and moments
- rotational speed
- motions / accelerations
- deflections
- misalignment or alignment allowances (relative to mountings).

Note 1: When items mentioned in [3.1.4] derive from previous wind turbine designs, the Society may request the Designer/Supplier/Vendor to proof good results of previous projects. Nevertheless, The Society may require these estimates to be verified through subsequent testing.

3.2 Power production

3.2.1 When the offshore wind turbine is running and connected to the electric load, the machine configuration should take into account any rotor imbalance, including the maximum mass and aerodynamic imbalances specified by the rotor manufacturer. In addition, deviations from theoretical optimum operating situations such as yaw misalignment and control system tracking errors should be taken into account in the load operational analysis.

3.2.2 The designer should ensure that the number and resolution of the normal sea states considered are sufficient to account for the fatigue damage associated with the full long term distribution of met-ocean parameters, whether for the duration of the service life, or for the life extension of the machine when so required in the project specification.

3.2.3 The designer is to consider the influence of marine conditions on the rotor - nacelle assembly and the rotor characteristics designed preferably for more than one specific site including wide range of marine environments.

3.2.4 The designer of the rotor may therefore assume generic marine conditions which reflect an environment at least as severe as is anticipated for the use of the specific wind turbine application. Depending on the dynamic properties of the support structure and the assumed design marine conditions, the designer may be asked in some cases to demonstrate by means of an appropriate analysis, that the marine environment has a negligible influence on the structural integrity of the rotor-nacelle assembly.

3.2.5 The designer should take into consideration a transient event triggered by a fault or the loss of electrical network connection while the turbine is producing power. Any fault in the control and protection system, or internal fault in the electrical system, significant for wind turbine loading (such as generator short circuit) are to be considered.

3.3 Start up

3.3.1 This design situation includes all the events that may take place during the transients from any standstill or idling situation to power production at the name plate rated power.

3.3.2 The number of occurrences should be estimated based on the control system behaviour during normal and abnormal predicted sea state conditions considering the frequency and most significant expected value for wave height for each individual sea state conditioned on the relevant mean wind speed.

3.4 Normal shut down

3.4.1 This design situation includes all the events resulting in loads on an offshore wind turbine during normal transient situations from a power production situation to a standstill or idling condition. The number of occurrences is to be estimated based on the control system behaviour.

3.5 Emergency shut-down

3.5.1 Loads arising from emergency shut-down are to be considered for normal sea state conditions including the combination of electrical and mechanical failures simultaneously with reactions from the yaw system and non-codirectionality of the wind and waves.

4 Mechanical Systems and components

4.1 General

4.1.1 For the purposes of this appendix, a mechanical system is any system that uses or transmits relative motion through a combination of shafts, links, bearings, slides, gears and other devices.

4.1.2 Within a wind turbine, these systems may include elements of the drive train, such as gearboxes, shafts and couplings, and auxiliary items, such as brakes, blade pitch controls, yaw drives and auxiliary items driven by electrical, hydraulic or pneumatic means.

4.1.3 All mechanical systems in the generator drive train and in the control and protection system are to be designed according to international recognized standards.

4.1.4 Particular care is to be taken to ensure that cooling and filtration systems can maintain the relevant operating conditions throughout the operating temperature range of each one mechanical system following the OEM specified maintenance procedures.

4.1.5 The remaining life of any component subject to wear is to be duly monitored.

4.2 Control and protection system

4.2.1 Provisions are to be made to ensure adequate protection of all components of the control and protection system against the effects of the marine environment.

4.2.2 The control and protection of the machine are to be suitable for the design and arrangement considering the particular dynamics and adequate response of the entire machine/platform with regards to wave loading, yawing and blade pitch control as well as the dampening of tower motions, roll motions, translations of the rotor in the plane of rotation or any other random behaviour of the entire floating unit.

4.2.3 Drivetrain including the gearbox is a critical subsystem with which the designer may encounter difficulties to monitor all components; nevertheless, he should be able to detect the most critical parts and rank the potential faults according to occurrence and associated downtime based on experience in the field.

Note 1: The loadings on drivetrains on floating wind turbines are very different from those used onshore, demanding higher Reliability, Availability, Maintainability and Serviceability than land-based designs; hence, the designer should detect and inform in the O&M Manual the schedule for inspections and preventive maintenance to be followed.

4.3 Drivetrain

4.3.1 A drivetrain analysis will be required to confirm the torsional stiffness value of the drivetrain specific gearbox loads due to dynamic amplification within the gearbox and to assess the influence of boundary (interface) conditions on internal gearbox loading.

4.3.2 All relevant parties in the design process should be included in the project as early as possible so to obtain the best possible design. A systematic process should then be agreed between the gearbox manufacturer and the wind turbine manufacturer to identify and evaluate all those items that may impact the reliability of the machine, such as but not being limited to:

- relevant design load cases
- system architecture
- interfaces
- interface requirements
- functional requirements for each element
- potential failure modes
- potential consequences of failure
- limited life components
- lubrication and cooling
- manufacturing quality demands
- service and maintenance
- monitoring
- transportation
- installation
- commissioning.

4.3.3 The analysis is to also include the fundamental forcing and natural frequencies of the generator drivetrain, as part of the wind turbine in addition to other frequencies such as gear mesh frequencies; rotational frequencies of the gearbox shafts and their harmonics.

4.3.4 Documentation of the drivetrain analysis is to, at a minimum, include:

- a campbell diagram including the main excitations in the system and relevant natural frequencies of the wind turbine system, the drivetrain (as part of the wind turbine), gear mesh frequencies, shaft frequencies and relevant harmonics
- stiffness, mass, inertia, and damping values of significant internal components, such as gears, shafts and bearings, and the complete drivetrain as used in the analysis.

4.4 Gearbox

4.4.1 Since the actual design details of the gearbox affects turbine dynamics, reasonable estimates and assumptions need to be made for some of the motions, deflections and other dynamic response at the interfaces. In any case, the experience from the designer and final supplier/vendor of the offshore wind turbine will be considered as the strongest driver for levelling the reliability between various components such that the required system reliability is achieved.

4.4.2 The various components are to be designed using component specific design standards such as ISO 76 and ISO 281 for rolling element bearings, or, ISO 6336 series for gears can be accepted as a primary reference for calculation taking into consideration:

- the target design reliability of each individual component
- the uncertainty of material properties at the given size range and target reliability
- the probability of general material deviations such as flaws, voids or inclusions
- the capability of the employed manufacturing processes for making parts compliant with the specifications
- the robustness of the design against variation in the environmental conditions, or the compliance and ability of the design to adapt to such variation
- the robustness of the design against variation in material and manufacture.

4.4.3 The frequency of occurrence of each load case such as magnitude, duration and frequency of occurrence of ultimate design load cases is to be included in the specification based on:

- operating conditions
- manufacturing processes
- quality control
- effectiveness of lubrication system (oil distribution, oil cleanliness, cooling)
- material properties.
- pitting resistance and bending strength. pitting and bending fatigue lives are to be a minimum number of hours specified by the wind turbine manufacturer but not less than the specified design life.
- load factors & load distribution factors
- dynamic factor
- mesh load factor
- transverse load factors
- fatigue load.

4.4.4 The safety factor for tooth bending is to be calculated according ISO 6336-3 method A or B.

4.4.5 The design is to ensure that the cooling and filtration systems can maintain the relevant lubrication state throughout the operating temperature range following the specified maintenance procedures.

4.4.6 The required cooling capacity is to be documented. Adequate cooling capacity is to be provided to remove the heat generated within the gearbox under the operating conditions.

4.4.7 If the gearbox contains a larger number of components which may have a detrimental influence on system reliability, all relevant manufacturing tolerances and displacements, including the gear safety factor, should include the material and load in the calculation of the face load distribution factor, should be in accordance with ISO 6336-1 or equivalent standard and the safety factor for pitting is to be calculated according to ISO 6336-2.

4.4.8 When the machine is furnished with gearboxes and bearings that because of their size and configuration are prone to suffer of skidding damage to bearings, low and transient load that can result in bearing failures earlier than rating life calculations, this issue is to be agreed between the gearbox manufacturer, bearing manufacturer, and wind turbine manufacturer through a full evaluation of the intervening factors such as:

- bearing design and size including cage design, cage guidance, internal geometry and surface conditions of rolling element and raceways.
- speed
- acceleration
- rate of change from unloaded to loaded conditions
- lubrication factors, such as quantity, viscosity, temperature and additives
- operating internal clearance
- size and location of the load zone including any preload
- elasticity of mounting
- effectiveness of coating or surface treatments (if applicable).

4.4.9 Attention is to be drawn to loads on a gearbox that being variable by nature, will typically include reversing loads, and where the amplitude and frequency of occurrence may depend on the control system response as well as on drivetrain dynamic properties.

4.4.10 To accommodate the loads mentioned in 18.10 without excessive relative movements, all types of shaft-hub connections are to have an adequate safety margin for transferring the reverse design torque only by interference without consideration of possible advantage from keys or other locking devices.

4.4.11 The operating loads in normal load direction should be transferred by interference alone with an adequate safety margin.

4.4.12 The risk of fretting corrosion due to micro-movements needs to be addressed in addition to accommodating torque, shaft bending and hub deflection.

4.4.13 The load capacities of gears are to be calculated, according to the ISO 6336 series or equivalent, using allowable stress numbers.

4.4.14 When influences are not covered by the reference tests, these are to be based and demonstrated on other tests proposed by the designer, or experience based on the influences described in ISO 6336-2 and ISO 6336-3. In any case, gear reliability should be based on factors such as power production load cases and start-up and braking procedures.

4.4.15 Extreme loads

The designer is to state under what conditions extreme loads may occur, whether being rotating or non-rotating situations, or related to power production or combination thereto.

4.4.16 Extreme design loads are to be specified in tables, whether these loads are being induced by forces, moments, and torques; including maximum load reversals and accelerations.

4.4.17 Design lifetime and reliability

The gearbox is to have high availability and a reliability being sufficient to limit maintenance and repair cost throughout the design life. The design life should at least be the same as for the wind turbine which should be at least 20 years; whereas the definition of components class s should be the same or equivalent to that indicated in IEC 61400-1 being a function of potential consequences of failures.

4.5 Yaw System

4.5.1

Due to the nature of the gearing, a large number of patents registered for this system combined with the design and reliability required for the yaw brake and the fatigue loads to which this components are exposed to, the Society will request a detailed description of the systems and components, materials used amidst the operational philosophy, including:

- moment distribution on yaw components during different yaw operations.
  - torque from aerodynamic loads.
  - yaw braking torque and stopping torque.
  - yaw acceleration response & control.
  - activation of yaw brakes to reduce gear backlash.
- load reduction designs and methods
- installation and maintenance possibilities
- the attachment of the yaw drives
- positioning of the of the yaw drives relatively to the ring gear
- stress distribution on the flanks
- lubrication between the shaft pinion and the ring gear.

4.5.2 The designer should pay special attention to the uncertainties related to the wind measurements on the nacelle and the yaw control methods based on the measurement of other parameters such as power production or actual yaw loads are becoming more apparent.

Note 1: Any unique design when not patented may require a special approval under the category of “New Technology” and subject to the requirements in Bureau Veritas Rule NI 525.

4.5.3 The yaw system may consist of means to maintain a fixed yaw orientation (e.g. hydraulic brakes), means to change that orientation (e.g. electric motors, gearboxes and pinions) and means to guide the rotation (e.g. a bearing).

4.6 Braking system

4.6.1 All brake devices are to be designed and maintained to keep the response time within acceptable levels

4.6.2 Monitoring of brakes are to be done automatically and subject to regular inspection.

4.6.3 The braking system is to be able to bring the rotor to idling mode or complete stop from any operation condition in any wind speed less than the wind speed limit defined by the designer for maintenance and repair.

4.6.4 The machine should have at least one braking system operating on an aerodynamic principle, as such acting directly on the rotor. If this recommendation is not met at least one braking system is to act on the rotor shaft or on the rotor of the wind turbine.

4.6.5 Brakes are to be designed to function even if their external power supply fails. A brake is to be able to keep the rotor in the full stop position for the defined wind conditions for at least one hour after the brake is applied. During longer periods of grid loss, it is to be possible to apply the brake by either an auxiliary power supply or by manual operation.

4.6.6 Where mechanical brakes are used for a protection function comprising friction devices applied by hydraulic or mechanical spring pressure, the remaining life of any wearing components, such as friction pads, is to be monitored by the control and protection system, which is to place the turbine in parked mode when insufficient material is available for a further emergency stop.

4.6.7 Load calculation is to be based on simulations including an appropriate range of the braking level. If the brake is able to slip in the standstill state at the minimum braking level, whenever the brake is to maintain the wind turbine in a stationary state, the period of slip in a turbulent wind must be sufficiently short to avoid overheating and brake performance impairment.

4.7 Pitch system

4.7.1 The pitch system may consist of means to adjust blade pitch angle (e.g. hydraulic actuators, electric motors, gearboxes, brakes and pinions) and means to guide the rotation (e.g. a bearing).

4.8 Bearings

4.8.1 For each of the defined interfaces, information is to be provided for describing the pertinent operating conditions and reactions including their dynamic excitations, such as forces and moments.

4.8.2 Bearing Specifications

The design of the bearing arrangement for a wind turbine gearbox happens across the interface between the gearbox manufacturer and the bearing manufacturer. For managing this critical interface without loss of relevant information, the gearbox manufacturer is to issue a detailed requirement specification for the bearing arrangement.

4.8.3 Bearing cages

Bearing cages that both guide and separate the rollers are to prove to be made out of suitable materials resistant to load, ageing, operating temperature and lubricant for the design lifetime.

The suitability of cage materials are to be agreed to between the purchaser, the wind turbine manufacturer and the gearbox manufacturer and are to be based on thorough evaluation of field experience.

4.8.4 Rolling bearings

The basis of rating analysis and bearing lives of rolling bearings for main shaft, gearbox and yaw related components and slew bearings when applicable are to be designed and manufactured in accordance with international recognized standards and are to be at least 20 years considering the expected amount of rotation during its lifetime and whether the rotations are continuous as in main shaft bearings or oscillating as in pitch and yaw bearings.

The calculation method is to consider the operating conditions while adjustment factors are to ensure that cooling and filtration systems can maintain the relevant operating conditions throughout the operating temperature range with the specified maintenance procedures.

4.8.5 Shaft and housing fits

Shaft and housing fits are to be selected to prevent or minimize relative motion.

4.8.6 When relative motion (both axial and rotational) between the bearing rings, the shaft and/or the housing may cause damage by fretting corrosion or adhesive wear, such as scoring; relative motion of the bearings rings are to not disturb the bearing kinematics, or provoke dislocation in the axial direction.

4.8.7 Other interference from varying load and elevated vibration level are to be taken into consideration to reduce the risk of bearing ring creep and fretting corrosion. Effects to consider when selecting the appropriate fits and tolerances include:

- condition of rotation
- magnitude of load
- bearing type
- bearing internal clearance
- temperature conditions
- required running accuracy
- design and material of shaft and housing
- displacement of non-locating bearing
- allowable hoop stresses
- ease of mounting and dismounting.

4.8.8 When tight bearing fits are not sufficient to prevent the relative motion of the bearing rings, or, in situations where tight fits are not desirable, the design is to contain appropriate additional means to either reduce the relative motion, or alleviate the damage associated with this, for example by means of pins, axial clamping, adhesives or appropriate surface coatings.

4.8.9 Bearing life rating

When calculated bearing lives are valid for comparison of different bearing options but may not reflect actual bearing lives under the actual service conditions, the designer will have to submit the results of analysis and justifications for the selected bearing model.

4.8.10 Static rating

The static safety factor is to be calculated using the actual internal load distribution from a detailed model following the approximation methods in accordance with recognized standards; whereas the calculation of the internal load distribution for the planet bearings is to include a gear load offset specified by the gearbox manufacturer.

4.9 Protection functions

4.9.1 The protection functions are to:

- be designed for fail-safe operation
- maintain the entire unit in a safe operation condition whether the rotor is turning or at rest, following a level of importance for the protection functions so in no case the design limits can be exceeded
- as practicable possible, protect the wind turbine from any single failure or fault in a power source
- have higher priority than control functions, but not higher than the emergency stop button, in accessing the braking systems and equipment for network disconnection when triggered
- not lead to malfunction of the protection functions
- be activated in such cases as:
  - over speed
  - generator overload or fault
  - excessive vibration
  - abnormal cable twist due to nacelle rotation by yawing.

4.9.2 Drivetrain loads

Drive train loads based on simulations are to include both, the mean braking level, and a minimum braking level that allows for minimum friction and application pressure predicted for the design.

4.9.3 If the brake is able to slip at the minimum braking level, when the brake is applied, it is to be designed to avoid overheating and brake performance impairment during, or preventing:

- situations resulting in axial motions at low loads
- situations including generator switch operations, for example for 2-speed generators
- situations resulting in torque reversals
- situations resulting in acceleration and deceleration of the drivetrain including those caused on the high speed side (e.g., caused by brake events, grid loss or grid frequency variation)
- situations at reduced rated power possibly resulting in torque reversals (e.g. noise reduction operation, block control operation)
- situations at wind speeds below cut-in (e.g. parked)
- situations caused by asymmetric loads from mechanical brake (normal or fault)
- situations resulting from actions at periodic maintenance
- situations representing the load variations during grid events
- situations resulting in high frequency inputs from the generator or high speed coupling.

APPENDIX 5 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 Risk assessment

1.2.1 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.

1.3 Safety

1.3.1 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.

1.3.2 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.

1.3.3 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.

1.3.4 Emergency procedures

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

1.3.5 Navigation

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

1.3.6 Signalisation

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

1.4 Lifting

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

1.4.2 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.

1.4.3 Padeyes intended for lifting operations should meet the design requirements of NR526.

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.

1.4.4 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 shut-down, emergency shut-down, behaviour at loss of load, behaviour at over-speed, 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.

Move Forward with Confidence

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