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GUIDELINES ON **CONSTRUCTION AND CLASSIFICATION OF FIXED OFFSHORE WIND TURBINE INSTALLATIONS (PROVISIONAL)**

JULY 2022

Guidelines

Construction and Classification of Fixed Offshore Wind Turbine Installations

(Provisional)

July 2022

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Section 1

Introduction and Scope

1.1 General Information

1.1.1 For General Information, Reference is made to Part 1, Chapter 1, Section 1 of the IRS Rules and Regulations for Construction and Classification of Fixed Offshore Structures.

1.2 Classification Information

1.2.1 In general, Chapter 1, Section 2 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures*, is also applicable to Fixed Offshore Wind Turbines (FXOWT).

1.2.2 A Fixed Offshore Wind Turbine (FXOWT) consists of the following major elements:

- Blades and Hub
- Nacelle (with all installed machinery & equipment)
- Tower
- Supporting Structure
- Secondary structures such as the boat landing, other platforms etc.
- Foundation

1.2.3 The blades, hub and nacelle together are known as the “Rotor Nacelle Assembly” (RNA). A schematic of a typical fixed offshore wind turbine is shown in Figure 1.2.3.

1.3 Scope of Classification

1.3.1 These Guidelines are applicable to fixed offshore wind turbine structures of the horizontal axis and upwind configuration.

1.3.2 The scope of Classification includes assessment of the supporting structure and the foundation. This includes the connection of the tower with the supporting structure. Where the Tower is also included within the scope of the Type Approval, then the Tower will not be included within the scope of Classification.

1.3.3 The RNA is not considered within the scope of Classification. As pre-requisite for Classification, the RNA is to be Type Approved in accordance with the IECRE OD-501 series by a Recognized Certification Body (RECB) who is a bona-fide member of IECRE (IEC system for Certification to Standards relating to equipment for use in Renewable Energy Applications). The documentation of the RNA in relation to the Type Certificate is to be submitted to IRS for its reference and information. IRS may also consider Type Certificate issued by a certification body in accordance with a certification scheme which is authorized by the National Authority of the state where the FXOWT is to be installed, provided that the certification body is recognized by the relevant National Authority. Table 1.3.3 shows the typical workflow of the scope.

1.3.4 In general, the Classification process consists of:

- A technical review of the design plans and related documents for a new Fixed Offshore Wind Turbine (FXOWT) to verify compliance with the Guidelines;

- Attendance at the fabrication and construction site(s) of the FXOWT by IRS surveyor(s) to verify construction is in accordance with the approved plans and the Rules/ Guidelines;
- Attendance by IRS surveyor(s) during installation and commissioning to verify conformance with the Rules/ Guidelines;
- Upon satisfactory completion of the above, the owner's/operator's request for the issuance of a Class Certificate will be considered by IRS and, if deemed satisfactory, the assignment of Class may be approved and a Certificate of Classification issued;
- Once in service, the owner is to submit the FXOWT to a clearly specified programme of periodical class surveys (refer Section 2) to be carried out to verify that the FXOWT continues to meet the relevant requirements for continuation of Class.

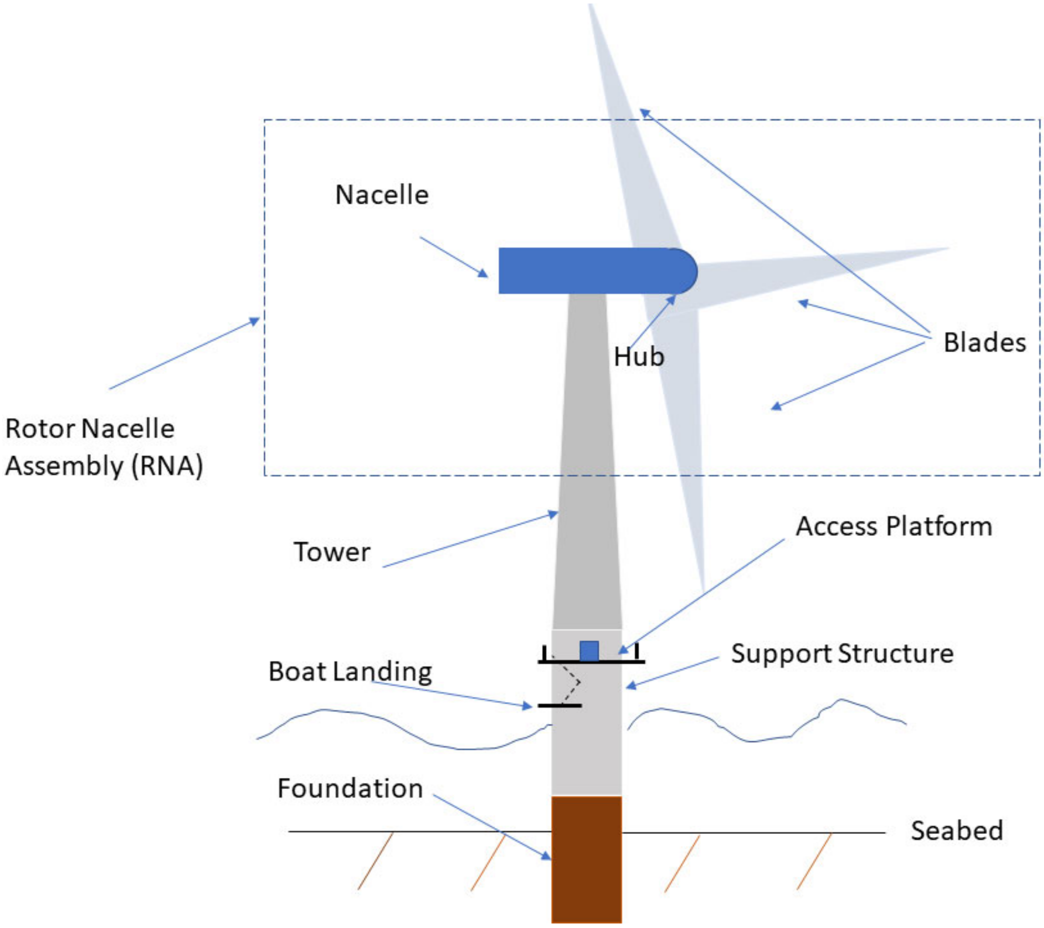

Figure 1.2.3 – Schematic of a typical FXOWT

Table 1.3.3 Scope of Classification		
Item	Covered by Type Certificate	Covered within IRS Scope
Blades	Yes	No
Nacelle (with installed machinery & Equipment)	Yes	No
Tower	Optional – If not covered by the Type Certificate, then it would be covered within IRS Scope	
Support Structures	No/ Optional	Yes
Secondary Structures (e.g. boat landing, access platforms etc.)	No/ Optional	Yes
Foundation	No/ Optional	Yes

1.3.5 When a Surveyor identifies corrosion, structural defects or damage to FXOWT Structure and Equipment which, based on these Guidelines and in the opinion of the Surveyor, affects the FXOWT's Class, remedial measures and/ or appropriate Conditions of Class would be imposed in order to retain Classification.

1.3.6 These Guidelines are developed on the assumption that the FXOWTs will normally be unmanned.

1.3.7 These Guidelines apply only to the FXOWT. Any other installation utilized within the wind farm (e.g. central power control station, offshore electric sub-stations which are not installed for wind power generation purpose etc.) are not covered within the scope of these Guidelines.

1.4 Character of Classification

1.4.1 The general principles regarding assignment of Character of Class and distinguishing mark, as detailed in Chapter 1, Section 2.4 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures*.

1.5 Class Notations

1.5.1 In addition to the Character of Class assigned by IRS, the FXOWT will also be applicable for Class Notations as given below:

a. Service Restrictions - This notation specifies the operational limitations of the FOWT considering its intended operation at the specific site where it is to be installed.

b. Description - In some cases, there may be a need to assign a 'description' to amplify the purpose or role of the FXOWT. In general, there would be no specific rule requirements to be complied with for assignment of a description.

E.g. A typical class notation would be as follows:

卐 SU, FXOWT, Operation at XXX site.

1.6 Identification of FXOWT

1.6.1 Identification of each FXOWT should be provided for by the Owner/Operator by a unique number as assigned by IRS. The identification plate is to be clearly visible on the FXOWT at the main entrance to the tower structure.

1.6.2 The identification plate should contain at least the following information clearly embossed in English:

.1 Unique identification number for the FXOWT
.2 Latitude and longitude of the particular location where the FXOWT is installed.
.3 Still water depth at the particular location
.4 Hub height
.5 Date of Installation and Commissioning (please also see Section 2, Section 3.1.7)

1.7 Definitions

1.7.1 *Axis*: Axis of rotation of wind turbine blades.

1.7.2 *Upwind*: A wind turbine configuration, whereby the rotor directly faces the wind.

1.7.3 *Rotor*: Assembly composed of the blades, hub, shaft and spinner.

1.7.4 *Nacelle*: An enclosed structure installed above the tower top which contains the necessary components for power generation, control systems, safety systems and others as applicable.

1.7.5 *Cut-in speed*: The lowest 10 minute steady wind speed at which the FXOWT generates electrical power.

1.7.6 *Cut-out speed*: The highest 10 minute steady wind speed at which the FXOWT generates electrical power. Beyond this wind speed, the wind turbine is in feathered mode.

1.7.7 *Hub Height*: The elevation of the center of the swept rotor area above the still water level.

1.7.8 *Fault*: Any anomaly or event which causes the malfunctioning of the FXOWT.

1.7.9 *Rated Wind Speed*: The lowest 10 minute steady wind speed above which the FXOWT delivers the rated power.

1.7.10 *Rated Power*: The maximum continuous electrical power output of the FXOWT in normal external environmental and normal operational conditions.

1.7.11 *Turbulence Intensity*: Ratio of deviation of wind speed standard deviation to the mean wind speed.

1.7.12 *Rotor Nacelle Assembly (RNA)*: A combination of the rotor and the nacelle.

1.7.13 *Fixed Offshore Wind Turbine (FXOWT)*: The Supporting Structure including the foundation (and tower if not included in the Type Certificate) upon which Rotor Nacelle Assembly is installed.

1.7.14 *Supporting Structure*: Supporting structure is a structure on which the tower with the RNA is installed. (This may typically be a jacket, monopole or tripod platform) This structure also transfers the load of the tower and RNA to the foundation.

Note: Supporting structure which is provided in form of a self-elevating unit(s) is not covered in these Guidelines. Such supporting structures will be specially considered by IRS, if provided.

1.7.15 *Foundation*: The structure which transfers loads from the tower, RNA and the supporting structure to the seabed. Foundation may be a pile foundation, shallow foundation or a gravity base structure.

1.7.16 *Wind Farm*: A group of FXOWTs and/ or Floating Wind Turbines (FOWTs) installed as a cluster at particular offshore site.

1.7.17 Definitions for items not covered in this Section may be referred in IEC 61400–3-1:2019.

1.8 Materials, Components, Equipment and Machinery

1.8.1 The materials used in the construction of FXOWT intended for Classification, or in the repair of FXOWT already classed, should be of good quality and free from defects and should be tested in accordance with the relevant requirements. The steel should be manufactured by an approved process at works recognized by IRS. Alternatively, tests to the satisfaction of IRS will be required to demonstrate the suitability of the steel.

Consideration may be given by IRS to accept the works approved by IACS Member Societies.

1.8.2 Certification of materials, components, and equipment is carried out on basis of following. Considering IRS and/or IEC requirements, as applicable:

- Type approval carried out by IRS
- Unit certification by IRS
- Alternative Certification Scheme by IRS (Refer Main Rules, Part 1, Chapter1, Section 4).

1.8.3 Mutual recognition of certificates, if type approved by an IACS Member Society or European Union recognized organization based on commonly agreed design requirements under Mutual Recognition Scheme between IRS and the recognized organization, may also be used as basis for certification of materials, components, equipment and machinery.

1.9 Request for Surveys

1.9.1 It is the responsibility of the Builders or Owners, as applicable, to inform IRS for supervision during new construction or FXOWT in service and to ensure that all surveys for issue of class certificate for new construction, and maintenance of class for FXOWTs in service are carried out.

1.10 Classification of New Constructions

1.10.1 In general, the requirements of Chapter 1, Section 3 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures* are also applicable to FXOWTs.

1.11 Suspension, Withdrawal and Deletion of Class

1.11.1 The general principles of suspension, withdrawal and deletion of class for fixed offshore steel structures (Refer Chapter 1, Sec 2.12 of the Rules) are applicable to FXOWTs also.

1.11.2 The Class of a FXOWT is also liable for suspension in case of invalidation/ suspension of the type certificate issued to the RNA. This is to be communicated promptly to IRS by the owner/ operator. Upon the reinstatement of the type certificate and satisfactory verification, IRS will reinstate the Class.

1.12 General Procedure for Classification of FXOWT not built under Survey of IRS

1.12.1 In general, the principles indicated in Chapter 1, Section 4 of the Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures should be followed, as relevant and applicable to FXOWTs.

1.12.2 The required plans and documentation for Classification are detailed in Section 1.14. Additional plans and information may be requested by IRS, as necessary.

1.12.3 Particulars/ details of the process of manufacture and testing of material of construction are to be provided. Consideration will however be given to waiving this where such particulars are not readily available, provided it can be established that the relevant FXOWT has been originally built under special survey of a Classification Society who is an IACS member and continues to be so classed with Classification Society who is an IACS member. In the case of FXOWT which has been originally built under the special survey of a classification society who is an IACS member but subsequently not maintaining class, it should additionally be possible to reasonably ascertain that no changes that would significantly affect the material specifications have taken place.

1.13 Alternative Designs

1.13 Deviation from the requirements in these Guidelines may be specially considered by IRS provided that adequate technical justification is provided to IRS for the same. Reference is also made to IRS *Guidelines on Alternative and Risk based Design Evaluation*.

1.14 Plans and Documentation

1.14.1 General

1.14.1.1 The following plans are in general to be submitted for approval or review (as applicable) but not limited to:

- General layout and arrangement of the FXOWTs and Wind farm (as applicable) – The plans are to clearly describe the overall configuration of the various RNAs, towers, supporting structures/sub-structures, foundations etc. through plans, elevations and profiles. Dimensions and weights (along with their centres of gravity) of various constituents (structure and equipment) are to be indicated in the layout and arrangement plans.

- Arrangement of boat landing, personnel access and/or other platforms, ladders, fenders etc.
- Scantlings of the supporting structures and foundations (including the secondary structures such as boat landing, personnel access platforms etc.)
- Scantlings of the Tower (if not included within the scope of the RNA Type Certificate)
- Pile structural drawings (if pile foundations are utilized). Load capacity of connection between structure and pile. Specifications of guide wires (if utilized)
- Structural Connection between tower and the RNA, tower and the supporting structure, supporting structure and the foundations
- Concrete structural drawings along with clear depiction of the arrangement and size of steel reinforcements etc. Detailed plans for the reinforcement at joints are also to be provided.
- Details of the concrete mixes being used.
- Details of the corrosion protection system.
- Wind Measurement data for the site as indicated in IEC 61400-3-1:2019
- Metocean data for the site.
- Geotechnical investigation reports of the site
- Seismic hazard report of the site.
- Analysis reports detailing load calculations on the various FXOWT components in accordance with the requirements of Section 5.
- Analysis reports detailing structural integrity evaluation of the FXOWT components in accordance with the requirements of Section 5.
- Analysis reports detailing evaluation of the foundation capacities and strength including the determination of consolidation/ support settlements and rotations over the service life.
- Quality assurance plan for construction (refer Section 2)
- Hazard identification and assessment report (refer Section 6.1.1)
- Typical Wind Turbine Configurations (tower, blade, nacelle etc.) to be installed.
- Operational manual (refer Section 1.14.2)
- Inspection, maintenance and repair manual.
- Plans related to safety of equipment and personnel (refer Section 6.2 and 6.3)
- All other relevant documentation to support the assessment of design in accordance with these Guidelines

1.14.2 Operational Manual

1.14.2.1 The Operational Manual of the FXOWT and the complete wind farm is to be submitted to IRS for review.

1.14.3 Information with reference to the Type and Component Certification of the RNA.

1.14.3.1 The Type and Component Certificates of the RNA should be submitted to IRS for information. The documentation should consist of all items included in the scope of the Type and Component Certificates issued to the RNA. This generally includes the data and measurements, analysis reports, model tests, prototype and full scale tests, FMEA of the systems and equipment, manufacturing evaluation, installation etc. (Document IECRE OD-501: 2018 (Type and Component Certification Scheme)) may be referred for the complete list of documentation to be submitted). IRS may request additional documentation, as deemed necessary.

Section 2

Surveys

2.1 General

2.1.1 This Section provides requirements for Surveys during construction, installation, commissioning and periodical surveys during the service life of the FXOWT.

2.1.2 Scope

2.1.2.1 Items included in the scope of survey include the FXOWT foundation, supporting structure and the Tower (if not included within the scope of the Type Certificate). Items such as the boat landing area of the FXOWT, personnel access and/or other platforms and ladder(s) and other structures of the FXOWT are also included within the scope of survey.

2.1.2.2 In addition, specific requirements of the Statutory Authorities are also to be complied with.

2.2 Surveys during Construction

2.2.1 General

2.2.1.1 Requirements for surveys during the construction of the FXOWT are indicated in this Section.

2.2.2 Quality Assurance

2.2.2.1 The yard including fabrication at the installation site (including construction with concrete material) should have a quality assurance program compatible with the type, size and intended function of the structure. A quality assurance plan (QAP) is to be developed and submitted to IRS for approval. Construction should be performed in accordance with the approved QAP.

2.2.2.2 Various inspection stages during construction should be addressed/ clearly indicated in the QAP.

2.2.3 The fabrication of structures including components will be monitored to ensure that all tests and inspections specified in the QAP are being carried out by competent personnel.

2.2.4 The construction monitoring provided by IRS is a supplement to and not a replacement for inspections to be carried out by the builder.

2.2.5 The QAP for construction of steel structures should include the following items as appropriate:

a) Material quality and traceability
b) Steel forming
c) Welder qualification and records
d) Welding procedure specifications and qualifications
e) Weld inspection
f) Tolerances, alignments and compartment testing

g) Corrosion control systems
h) Non-destructive testing
i) Key control points for inspections

2.2.6 Records of the construction activities performed should be maintained and made available to the Surveyor upon request.

2.2.7 For construction using concrete material, the following aspects (but not limited to) should be included in the QAP:

a) Review of documentation including preparation bar bending schedules, concrete mixes etc.
b) Inspection of formwork including the arrangement of reinforcement as per the approved drawings
c) Verification of the coarse, fine aggregates, cement grades, water quality used in the concrete mix
d) Verification of preparation of the concrete mix including ascertaining the condition of the concrete mixing equipment
e) Inspection during casting/ pouring of the concrete
f) Inspections during curing of the concrete
g) Inspection of pre-stressing (as applicable)
h) Inspection of the final concrete structure
i) Inspection of test records and or/ documentation (e.g. receipt of materials as per specifications, aggregate gradation tests, cement tests, steel reinforcing bar tests, water quality tests, concrete mix compressive tests, ambient conditions during casting of concrete etc.).

2.2.8 Records of the construction activities performed using concrete should be maintained and made available to the Surveyor upon request.

2.3 Surveys during Installation and Commissioning

2.3.1 Requirements for Surveys during installation and commissioning of the FXOWT are indicated in this sub-section.

2.3.2 The installation and commissioning plan is to be submitted to IRS for approval (only for those items which are covered under the scope of Classification)

2.3.3 The following installation activities of the FXOWT would be witnessed by the Surveyor:

a) Installation of piles or shallow foundations (as applicable). (Relevant requirements within Rules and Regulations for the Construction and Classification of Fixed Offshore Structures also applicable for this item)
b) Installation of supporting structure (in case of activities pertaining to in-situ casting and curing of concrete, these activities are to be witnessed at critical hold points by the surveyor as indicated in the QAP).
c) Installation of the tower
d) Welding and NDT performed on the site during installation.
e) Confirmation of any damage on items (covered under scope of Classification) which occurs during the installation of the tower, the RNA and any subsequent activities which may include hook-up of the power cable system. This activity is relevant prior to, as well as after the final installation.

2.3.4 The Surveyor is to be provided with a copy of the Type Certificate of the wind turbine.

2.3.5 Installation of the items indicated in 2.2.7 should be in accordance with the construction tolerances considered during the design. If damage or deviations from the plans occur during the installation, then a report is to be submitted to IRS with assessment of the significance of such damage/ deviations. The necessary remedial actions are to be additionally submitted to IRS.

2.3.6 Surveyors are to be provided with safe means of access to the FXOWT for undertaking Surveys.

2.3.7 Upon successful installation of the FXOWT (along with the RNA), a certificate will be issued by IRS with the installation completion date. This date would be considered as the anniversary date for future surveys.

2.4 Periodical Surveys

2.4.1 General

2.4.1.1 Annual and Special Surveys are to be performed for maintaining the FXOWT under Classification.

2.4.1.2 Any damage to FXOWT is to be promptly reported to IRS along with the necessary repair actions, which are to be acceptable to IRS.

2.4.1.3 IRS Surveyors are to be provided safe access to the FXOWT to facilitate the surveys.

2.4.1.4 A Survey programme should be developed by the Owner/Operator and submitted to IRS for approval. Risk based inspection programme may also be considered by IRS provided that such a programme is supported by satisfactory supporting documentation.

2.4.2 Annual Surveys

2.4.2.1 Surveys of the FXOWT should be performed annually within three months on either side of the anniversary date.

2.4.2.2 Annual Surveys generally consist of a visual inspection of the FXOWT structure above water. Special attention should also be provided to the structure(s) in the splash zone to detect excessive corrosion wastage and damage. IRS surveyor may expand the scope of inspection if deemed necessary based upon the condition of the structures as adjudged from the preliminary visual inspection.

2.4.2.3 Assessment of the degree of marine growth should be carried out during Annual Surveys. Marine growth should be removed where it is found to be thicker than the original approved design/ plans. If the Owner intends to leave the marine growth greater than what is allowed in the approved design, as a minimum, then the Owner should submit an in-place analysis to show that the structure would be able to withstand the additional environmental loads resulting from the maximum marine growth proposed to be maintained.

2.4.2.4 Documentation/ certificate and/or records of regular servicing and maintenance and or/repairs performed on the RNA by the authorized and qualified persons should be submitted to the IRS Surveyor for review.

2.4.2.5 The validity of Type Certificate of the wind turbine is to be confirmed by the Surveyor.

2.4.3 Special Surveys

2.4.3.1 Special Surveys of the FXOWT are to be performed once in every five years.

2.4.3.2 In addition to Annual Surveys, the following are to be included in the scope of the Special Surveys:

- .1 Underwater inspection of the submerged structure under water to detect corrosion and/ or damage. Potential measurements are to be taken to gauge the effectiveness of the corrosion protection system.
- .2 Underwater inspection of the seabed and scour around the piles/ shallow foundation locations to detect potential support rotations and settlements. Condition of the scour protection system (if installed) is to be confirmed from the underwater inspection.
- .3 Underwater inspection to detect any abnormal marine growth
- .4 Thickness measurements at random locations and particularly in the splash zone.
- .5 NDT of critical structural joints

2.4.3.3 Underwater inspections and NDT are to be performed by respective firms approved as service suppliers and under monitoring by the IRS Surveyor.

2.4.4 Inspections after extreme environmental events (hurricanes, cyclones, tsunamis etc.)

2.4.4.1 Inspections are to be performed after an extreme event has occurred which may be a cyclone, hurricane or tsunami. These inspections would also include inspection of the underwater portions of the FXOWTs. These inspections are aimed to detect any damages arising from such events and any such damages should be promptly reported to IRS.

2.4.4.2 It is preferred that such inspections are carried out in presence of the IRS Surveyor. However, if this may not be possible then the report of such inspections should be submitted to IRS along with any remedial action plans in case of damages which have been detected. Based upon the report, IRS may decide to expand the scope and perform a complete Survey.

Section 3

Materials and Welding

3.1 General

3.1.1 In general, the materials used for construction or repair of FXOWTs, which are classed or intended to be classed with IRS are to be in accordance with the requirements of Chapter 3 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures.*

3.1.2 Materials complying with recognized national or international standards like API RP-2A may also be accepted by IRS. If other materials are intended to be used, the relevant specifications with all details required for appraisal are to be submitted to IRS for approval.

3.1.3 The materials selection process is to reflect the overall philosophy regarding design life, inspection and maintenance, safety and environmental profile, failure risk evaluations and other specific project requirements.

3.1.4 For construction using concrete as material, compliance with recognized standards such as ACI 318, ACI 357, Eurocode 2 (EC 2) etc. is required keeping in view that the concrete will be exposed to a marine environment throughout its lifetime.

3.1.5 Novel materials not covered within this Chapter will be specially considered by IRS. Reference is made to the IRS *Guidelines for Alternative and Risk based Design Evaluation.*

3.2 Corrosion Protection

3.2.1 Materials are to be protected from the effects of corrosion by the use of a corrosion protection system including the use of coatings. The intensity of corrosion of an unprotected steel structure in seawater varies markedly with its position relative to the sea levels. The splash zone above the mean tide level is the most severely attacked region due to continuous contact with highly aerated sea water and the erosive effects of spray, waves and tidal actions.

3.2.2 In general, corrosion protection systems are to be provided in accordance with Chapter 3, Section 2 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures.*

3.3 Welding

3.3.1 In general, welding for steel structures is to comply with the requirements of a recognized specification, such as the Structural Welding Code – Steel of the American Welding Society, (AWS), D.1.1.

3.3.2 Requirements in Chapter 3, Section 3 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures* are to be complied with.

Section 4

External Site Conditions

4.1 Scope

4.1.1 Environmental conditions for the specific site where the FXOWT(s) are to be installed are to be determined through measurements and/ or utilization of available data and submitted to IRS.

4.1.2 Environmental conditions are to be determined using measurements from the specific site. Measurement data along with detailed technical reports for determining the characteristic parameters for evaluating the loads are to be submitted to IRS. The models and assumptions used during processing of such data to compute the loads including limitations (if any) are to be clearly documented.

4.1.3 Data from sites in proximity to the intended site of installation may be considered by IRS provided that they represent actual environmental conditions at the intended site. Use of such data is to be declared at an early stage and is to be acceptable to IRS.

4.1.4 The following external site conditions are covered within the scope of this Section but not limited to:

- Wind Conditions
- Wave Conditions
- Current Conditions
- Cyclonic Conditions
- Tidal Conditions
- Air and Sea temperatures
- Site Humidity, Ambient and Peak Solar radiation, air densities, Salinities etc.
- Site Geotechnical Conditions
- Seabed movements and Scour
- Seismic events
- Ice Conditions
- Marine Growth
- Lightning

4.1.5 The FXOWT design is to consider at least the factors as listed in this Section.

4.2 Wind Conditions

4.2.1 General

4.2.1 The various wind load scenarios to be considered in the design of the FXOWT are covered in this sub-section.

4.2.2 The scenarios indicated are in accordance with IEC 61400 series of standards.

4.2.2 Normal Wind Profile (NWP)

4.2.2.1 The longitudinal mean wind speed profile as a function of the vertical elevation from the still water level is indicated in the form of a power law equation as follows:

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.14}$$

V(z): 10 minute longitudinal mean wind speed at an elevation *z* above the still water level (m/s)
V_{hub}: 10 minute wind speed at the hub (m/s)
z: Vertical elevation of the point where V(z) is to be determined above still water level (m)
z_{hub}: Vertical elevation of the hub above the still water level (m)

4.2.3 Wind Spectrum and Spatial Coherence Model

4.2.3.1 Wind Spectrum and Spatial Coherence are to be modeled on the basis of actual data measured at the site. The Kaimal spectrum as described in Annex B of IEC 61400-1: 2018 can be applied for this purpose, unless data indicate otherwise.

4.2.4 Normal Turbulence Model (NTM)

4.2.4.1 Normal Turbulence is defined as the 90% quantile of the standard deviation of wind speed conditioned on the 10 minute mean longitudinal wind speed at the hub height. In absence of actual data for turbulence, the standard deviation of turbulence can be taken as follows:

$$\sigma_1 = \frac{V_{hub}}{\ln(z_{hub}/z_0)} + 5.12 I_{15}$$

Where, V_{hub} and z_{hub} are as defined in Section 4.2.2.
I_{15}: Turbulence intensity evaluated at 10 minute mean longitudinal speed of 15 m/s at the hub
z_0: Parameter evaluated from solution of the equation as shown below:

$$z_0 = \frac{A_c}{g}\left[\frac{0.4V_{hub}}{\ln(z_{hub}/z_0)}\right]^2$$

Where:
A_c: Charnock's constant. This is recommended to be taken as 0.11 for open sea and 0.034 for near coastal locations.
g: Acceleration due to gravity (m/s^2)

4.2.5 Extreme Turbulence Model (ETM)

4. 2.5.1 The Extreme Turbulence Model is used with the Normal Wind Profile (see Section 4.2.2) and the standard deviation of the longitudinal wind speed component is represented by the equation:

$$\sigma_1 = cI_{15}\left(0.072\left(\frac{V_{avg}}{c} + 3\right)\left(\frac{V_{hub}}{c} - 4\right) + 10\right)$$

Where,
c: parameter not to be taken less than 2 m/s
I_{15}: Parameter as described in Section 4.2.4

V_{avg}: Average annual speed at hub height

4.2.6 Extreme Direction Change (EDC)

4.2.6.1 The Extreme Direction Change is a transient phenomenon expressed by the magnitude of the change in direction multiplied by the transition function. The magnitude of extreme direction change of wind is to be evaluated as shown in the below equation:

$$\theta_{max} = \pm 4 \tan^{-1}\left(\frac{\sigma_1}{V_{hub}\left(1 + 0.1\left(\frac{D}{\Lambda_1}\right)\right)}\right)$$

Where,

σ_1: std. deviation, as in Section 4.2.5

D: Diameter of the Rotor

Λ_1: Longitudinal Turbulence Scale Parameter evaluated at hub height as below:

$$\Lambda_1 = 0.7 z_{hub} \; if \; z_{hub} < 60m$$
$$\Lambda_1 = 42 \; if \; z_{hub} \geq 60m$$

4.2.6.2 The magnitude θ_{max} is limited to the interval -180° to +180° degrees.

4.2.6.3 The transition function of the extreme direction change in terms of temporal variation is shown as below:

For $t < 0$

$$\theta(t) = 0$$

For $0 \leq t \leq T$

$$\theta(t) = \pm 0.5\theta_{max}\left(1 - cos\left(\pi t/_T\right)\right)$$

For $t > T$

$$\theta(t) = \theta_{max}$$

Where t is the time in seconds and T = 6 seconds is to be considered as the total duration over which the direction change takes place.

4.2.6.4 The Normal Wind Profile model is to be considered as shown in Section 4.2.2.

4.2.7 Extreme Operating Gust (EOG)

4.2.7.1 The Extreme Operating Gust magnitude is presented as described in below equation:

$$V_{gust} = MIN(A, B)$$
$$A = 1.35(V_{e1} - V_{hub})$$
$$B = 3.3\left(\frac{\sigma_1}{1 + 0.1\frac{D}{\Lambda_1}}\right)$$

Where σ_1 is defined in Section 4.2.5; D and Λ_1 are defined in Section 4.2.6.

4.2.7.2 The time dependent Wind Speed Profile is represented by the following equation:

For $0 \le t \le T$

$$V_{z,t} = V_z - 0.37 V_{gust} sin\left(\frac{3\pi t}{T}\right)\left(1 - cos\left(\frac{2\pi t}{T}\right)\right)$$

Where,

T: Duration of the gust to be taken as 10.5 seconds.

4.2.7.3 V(z) is to be taken in accordance with Section 4.2.2.

4.2.8 Extreme Coherent Gust with Direction Change (ECD)

4.2.8.1 The extreme coherent gust with direction change is to have a magnitude as shown below:

$$V_{cg} = 15\ m/s$$

4.2.8.2 The time dependent relationship of wind speed is as follows:

For $t<0$,

$$V_{z,t} = V(z)$$

For $0 \le t \le T$

$$V_{z,t} = V(z) + 0.5 V_{cg}\left(1 - cos\left(\frac{\pi t}{T}\right)\right)$$

For $t>T$

$$V_{z,t} = V(z) + V_{cg}$$

Where, T is to be taken as 10 seconds as the rise time and V(z) is taken as given in Section 4.2.2.

4.2.8.3 The rise in wind speed is to be simultaneously considered with change in direction of wind. The magnitude of change of direction (in degrees) is to be modeled as follows:

For V_{hub} < 4m/s

$$\theta_{cg} = 180$$

For $V_{hub} \ge$ 4m/s

$$\theta_{cg} = \frac{720}{V_{hub}}$$

4.2.8.4 The time dependent change in direction of wind is expressed as follows:

For $t<0$

$$\theta(t) = 0$$

For $0 \le t \le$ T

$$\theta(t) = \pm 0.5\theta_{cg}\left(1 - cos\left(\frac{\pi t}{T}\right)\right)$$

For $t > T$

$$\theta(t) = \pm\theta_{cg}$$

Where *T* is the rise time to be taken as indicated in 4.2.8.2.

4.2.9 Extreme Wind Model (EWM)

4.2.9.1 The extreme wind model is expressed through the wind speed profile as follows:

$$V(z) = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.11}$$

4.2.9.2 The extreme wind model as indicated in 4.2.9.1 corresponds to a return period of 50 years.

4.2.9.3 The standard deviation of longitudinal turbulent wind is to be taken as follows:

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

4.2.10 Extreme Wind Shear Model (EWS)

4.2.10.1 The extreme wind shear model prescribes the transient longitudinal and horizontal wind speeds to be considered.

4.2.10.2 The longitudinal transient wind speed is to be considered as follows:

For 0 ≤ t ≤ T

$$V_{z,t} = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.14} \pm V'\left(1 - cos\left(\frac{2\pi t}{T}\right)\right)$$

Where, *V'* is expressed as:

$$V' = \left(\frac{z - z_{hub}}{D}\right)\left(2.5 + 0.2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{0.25}\right)$$

Where, z, z_{hub} are to be taken as indicated in Section 4.2.2, D and Λ_1 are to be taken as indicated in Section 2.6, σ_1 is to be considered as indicated in Section 4.2.4.

β is to be taken as 6.4 and *T* is to be taken as 12 seconds.

For *t* > *T*

$$V_{z,t} = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.14}$$

4.2.10.3 The horizontal transient wind speed is to be considered as follows:

For 0 ≤ *t* ≤ *T*

$$V_{y,z,t} = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.14} \pm V''\left(1 - cos\left(\frac{2\pi t}{T}\right)\right)$$

Where *V''* is expressed as shown below:

$$V'' = \left(\frac{y}{D}\right)\left(2.5 + 0.2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{0.25}\right)$$

All parameters are to be taken as indicated in this Section.
'*y*' is to be taken as the horizontal transverse distance of the reference point from the hub.

For $t > T$

$$V_{y,z,t} = V_{hub}\left(\frac{z}{z_{hub}}\right)^{0.14}$$

4.2.10.4 The sign for the horizontal transient wind shear is to be chosen so as to represent the worst case scenario for the response.

4.2.10.5 The extreme wind shears in the transient and horizontal directions are not to be applied simultaneously.

4.3 Wave Conditions

4.3.1 General

4.3.1.1 Wave conditions are to be based upon the data and/ or measurements available at the intended site of installation.

4.3.1.2 The wave conditions to be used for the analysis of the FXOWT are covered in this sub-section.

4.3.1.3 The wave conditions indicated are in accordance with IEC 61400-3-1: 2019.

4.3.2 Normal Sea State (NSS)

4.3.2.1 Normal Sea State (NSS) is a sea state represented by a significant wave height, peak spectral period and wave direction. This is to be determined considering joint probability (or conditional probability) of occurrence along with the 10 minute average longitudinal wind speed at the hub height.

4.3.2.2 For Fatigue analysis, a sufficient number of sea states are to be considered by the designer in order to ensure accurate determination of the fatigue damage.

4.3.2.3 For strength calculations, a number of sea states are to be considered based upon the expected values of significant wave height conditional to the mean longitudinal wind speed at the hub. A range of peak spectral periods are to be considered for such significant wave heights to determine the response of the structure which is the most onerous.

4.3.3 Severe Sea State (SSS)

4.3.3.1 The Severe Sea State (SSS) is represented by a combination of mean hub speeds and significant wave heights such that their joint occurrence corresponds to a return period which is not less than 50 years. The SSS is utilized for the evaluation of strength of the FXOWT.

4.3.3.2 The Severe Sea State is utilized in combination with normal wind conditions

4.3.3.3 A range of appropriate peak spectral periods is to be selected for each significant wave height as determined above.

4.3.4 Extreme Sea State (ESS)

4.3.4.1 The Extreme Sea State (ESS) is a design sea state with a return period of not less than 50 years.

4.3.4.2 The ESS is to be determined from analysis of site specific met-ocean data. The following are to be considered:

a) Significant wave height with return period of 50 years assuming 3 hours reference period
b) Significant wave height with return period of 1 year assuming 3 hours reference period.
c) Extreme individual wave height with a return period of 50 years and associated range of wave periods
d) Extreme individual wave height with return period of 1 year and the associated range of wave periods
e) Extreme crest height with return period of 50 years.

4.3.4.3 The possibility of occurrence of breaking waves at the specific site is also to be considered, depending upon the water depth, sea bed slope, wave height, period and steepness. Reference is also made to Annex B of IEC 61400-3-1: 2019 for more details.

4.4 Current Conditions

4.4.1 General

4.4.1.1 The current conditions to be considered for the design of FXOWTs are covered in this sub-section.

4.2 Normal Current Model (NCM)

4.4.2.1 Normal Current Model (NCM) is to be considered for evaluation of the strength. It is thus relevant to be applied the Normal Sea State (SSS) and the Severe Sea State (SSS) wave load cases. The current velocities are to be selected based upon due consideration of joint probability with the 10 minute average longitudinal wind speed at the hub under consideration.

4.3 Extreme Current Model (ECM)

4.4.3.1 Extreme Current Model (ECM) is to be used for strength evaluation cases in combination with an Extreme Sea State Condition. The Currents associated with the Extreme Current Model may be selected based upon a 1 or 50 year return period taking due account of the joint probability distribution with the wind.

4.5 Water Levels, Tides, Storm Surges

4.5.1 General

4.5.1.1 The variation of water level at the site is to be considered during the determination of loads.

4.5.1.2 The water level variation at the site is to be considered to determine appropriate location of the splash zone, boat landing areas and suitable locations of the fenders.

4.5.1.3 Additional details may be referred in IEC-61400-3-1:2019.

4.5.2 Mean Sea Level (MSL)

4.5.2.1 Mean Sea Level (MSL) is the average daily sea water level recorded at the site. The period to be considered for the determination of average is to be of sufficient length and in general not to be considered less than 5 years.

4.5.3 Normal Water Level Range (NWLR)

4.5.3.1 Water Level Range (WLR) is the difference between the daily water levels at the highest astronomical tide and the lowest astronomical tide.

4.5.3.2 NWLR is to be evaluated generally considering wave conditions with a return period of 1 year. For this purpose, the site specific long term probability distribution of the water level range at the site is to be available.

4.5.3.3 Where indicated (Refer Section 5), load calculations are to be to be performed considering a water level within the NWLR so as to obtain the most severe responses.

4.5.4 Extreme Water Level Range (EWLR)

4.5.4.1 Extreme Water Level Range (EWLR) is the water level range which is to be evaluated considering wave conditions with return period of 50 years of more.

4.5.4.2 Where indicated (Refer Section 5), load calculations are to be to be performed considering a water level in the EWLR so as to obtain the most severe responses.

4.6 Geotechnical Conditions

4.6.1 Requirements

4.6.1.1 Site-specific geotechnical conditions are to be determined and considered in the design of the FXOWT foundation structure.

4.6.1.2 The site investigation is to be carried out consisting of the following but not limited to:

a) Geological survey at site
b) Bathymetric survey of the sea floor
c) Soil investigation and testing.

4.6.1.3 Detailed requirements for the determination of geotechnical conditions at the site are given in Chapter 7, Section 2 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Structures*.

4.7 Seabed Movement and Scour

4.7.1 General

4.7.1.1 The sea-bed stability is to be assessed. It is to be determined whether the bathymetry and soil configuration at the site require consideration of the possibility of slope failure, seabed movements, etc. In general, settlement and soil liquefaction are to be taken into account for the design of gravity base foundations.

4.7.1.2 Seabed movement and scour can result in removal of vertical and lateral support for foundations, causing undesirable settlements and displacements of shallow foundations, overstressing of foundation elements and change in dynamic properties of the wind turbine structure. Where scour is a possibility, it is to be taken into account in design and/ or its mitigation is to be considered.

4.7.1.3 The extent of scour and the required scour protection at the wind turbine site is to be determined either:

- on the basis of previous records/ data from nearby sites or sites with similar sea floor characteristics; or
- from model tests; or
- from calculations calibrated by prototype or model tests.

4.7.1.4 Analysis of seabed movement and scour and; the design of appropriate protection is to be in accordance with ISO 19901-4:2016.

4.8 Marine Growth

4.8.1.1 Requirements are specified in Section 5.1.4.

4.9 Ice Loads

4.9.1.1 Requirements are specified in Section 5.1.5.

4.10 Seismic Events

4.10.1.1 An assessment of the seismic activity at the site is to be carried out. Attention is to be paid to identification of fault zones, extent and geometry of faulting and possible attenuation effects due to conditions in the region of the field.

4.10.1.2 The assessment is to be utilized to determine the earthquake loads as described in Section 5.1.6.

4.11 Temperature Conditions

4.11.1.1 Temperature data pertaining to air, sea and seabed at site are to be available in terms of return periods and associated extreme high and low values.

4.11.1.2 In general, the temperature data is also used to evaluate selection of structural materials, ambient conditions for design of equipment and machinery and assessment of thermal stresses.

4.11.1.3 In the absence of site-specific data, the extreme ambient air temperature range for FXOWTs may be taken as -15ºC to +40ºC.

4.11.1.4 In the absence of site-specific data, the extreme ambient water temperature range for FXOWTs may be taken as -2ºC to +35ºC.

4.12 Lightning

4.12.1.1 A lightning protection system is to be provided in accordance with IEC 61400-24:2019.

4.13 Electrical Network Conditions

4.13.1.1 The requirements specified in IEC 61400-3-1: 2019 are to be complied with.

4.13.1.2 In the absence of site specific data, a loss of electrical connection for a continuous period of 3 months is to be considered as the extreme condition.

Section 5

Structural Analysis and Design

5.1 Loads

5.1.1 Scope

5.1.1.1 The loads and load combinations to be considered during design of the FXOWT support structures and foundations along with the recommended methods of structural design are indicated in this Section.

5.1.2 Static Loads

5.1.2.1 Gravity loads are static loads arising from various masses. These include but are not limited to the following:

- Mass of blades, nacelle, hub including the equipment and outfitting of the nacelle
- Mass of the tower
- Mass of the supporting structure/sub-structure (This also includes mass of the boat landing, access platform and all outfitting)
- Foundation

Where applicable, the submerged weights are to be used.

5.1.2.2 Hydrostatic pressure loads are to be considered for the submerged structural members of the FXOWT.

5.1.2.3 Live loads as applicable on the boat landing, access and other platforms are to be considered in the analysis. These may be taken as quasi-static loads.

5.1.3 Environmental Loads

5.1.3.1 General

.1 Environmental loads arise due to various external conditions as indicated in Section 4.

5.1.3.2 Aerodynamic Loads

.1 Aerodynamic loads are caused by the airflow and its interaction with stationary and moving parts of the turbines.

.2 These loads depend upon several factors such as the geometric shape, dynamic stiffness and inertia characteristics of the blades, hub and the nacelle, the speed of rotation of the rotor, air density, type of wind load case under consideration.

.3 For FXOWT within a wind farm, the wake and shadow effects from the other FXOWT in the proximity are to be considered. Such influence is to be typically considered for other FXOWTs located within a horizontal distance of at least 10 times the rotor diameter. IEC 61400-3-1: 2019 may be referred for additional guidance.

.4 Aerodynamic loads are to be evaluated by using recognized techniques and recognized software which are acceptable to IRS.

.5 Model tests and/or full scale tests may be required by IRS in addition to the evaluation of the aerodynamic loads as above.

5.1.3.3 Wind Loads on the Tower, Supporting Structure and the Foundation

.1 The wind forces on the tower, structural members of the Supporting Structure, foundation which are situated above the waterline (including the boat landing platform and other miscellaneous structures) are to be evaluated. The wind forces normal to the exposed service can be evaluated using the equation as follows:

$$F_{Wind} = 0.5\frac{\rho C_s A_{surf} V^2}{g} \qquad [N]$$

Where,
C_s: Shape Coefficient as shown in Table 5.1.3.3.1
A_{surf}: Area of the exposed surface normal to the wind direction [m^2]
V: Velocity of the wind [m/s], this can be considered at the centroid of the member (considering the vertical co-ordinate of the member above sea level)
g: Acceleration due to gravity [m/s^2]

Table 5.1.3.3.1: Shape Coefficients

Shape	C_s
Spherical	0.4
Cylindrical	0.5
Major Flat Surfaces	1.0
Isolated Structural Shapes (angles, beams, channels)	1.5
Underdeck areas (exposed beams and girders)	1.3

.2 Shielding effect may be considered when a structural member is shielded from direct exposure to the wind by being close enough behind another member. Generally, the two structural components are to be separated by not more than seven times the width of the windward component for a reduction to be taken in the wind load on the leeward member.

.3 Dynamic effects due to the cyclic nature of gust wind and cyclic loads due to vortex induced vibration are to be taken into account where relevant. Consideration is to be given to wind loads on members during transportation phase.

5.1.3.4 Wave Loads

.1 Forces caused by the action of waves on the exposed FXOWT structural members are to be taken into account in the structural design. Theories used to calculate wave forces and to select relevant force coefficients are to be acceptable to IRS.

.2 Hydrodynamic characteristics of the structure are to be considered in selecting the method to estimate design wave loads.

.3 Forces on appurtenances such as boat landings, fenders or bumpers, walkways, stairways, grout lines, and anodes are to be considered for inclusion in the hydrodynamic model of the structure. Forces on some appurtenances may be important for local member design. Appurtenances are generally modeled by non-structural members that contribute equivalent wave forces.

.4 For small members (which do not significantly modify the incident wave. This condition is satisfied if D/L < 0.2, where D is a characteristic dimension of the structure (e.g., diameter of structural members in the direction of wave propagation, and L is the wave length)), the Morison equation may be used to calculate the force exerted by waves on a cylindrical object. The wave force can be considered as the sum of a drag force and an inertia force, as shown below:

$$F_{wave} = F_{drag} + F_I \qquad \text{[N/m]}$$

Where,
F_{wave}: hydrodynamic force vector per unit length along the member, acting normal to the axis of the member
F_{drag}: drag force vector per unit length
F_I: inertia force vector per unit length

5.1.3.4.5 The drag force per unit length is to be evaluated as shown below:

$$F_{drag} = 0.5\rho C_d D u_n |u_n| \qquad \text{[N/m]}$$

Where,
ρ: mass density of sea water [kg/m^3]
C_d: drag coefficient (dimensionless)
u_n: component of the velocity vector, normal to the axis of the member [m/s]

5.1.3.4.6 The inertia force per unit length is to be evaluated as shown below:

$$F_I = \rho C_M A_s a_n \qquad \text{[N/m]}$$

Where
a_n: component of the water particle acceleration normal to the axis of the member [m/s^2]
C_m: inertia coefficient based on the displaced mass of fluid per unit length (dimensionless)
A_s: Cross sectional area of the member [m^2]

.7 Values of u_n and a_n for use in Morison's equation are to be determined using wave theories appropriate to the wave heights, wave periods and water depths being considered. Drag and inertia coefficients vary considerably with section shape, Reynold's number, Keulegan-Carpenter number and surface roughness. They are to be based on reliable data obtained from literature, model or full scale tests.

.8 Drag coefficient and Inertia coefficient are to be estimated in accordance with procedure given API RP 2A (WSD). Values for more complicated structural elements can be accepted from competent institution, with the approval from IRS. In the case of pile supported template type structures, the normal ranges of values of C_d and C_m are 0.6 to 1.2 and 1.5 to 2.0 respectively.

.9 Morison equation, as stated above, ignores the convective acceleration component in the inertia force calculation as well as lift forces, impact related slam forces, and axial Froude-Krylov forces. These forces are to be determined additionally as applicable.

.10 For structural configurations which may significantly alter the incident waves, diffraction theories are to be utilized to determine the relevant wave loads. Diffraction theories may be based on sink-source methods or finite fluid volume methods. For simple geometric shapes, analytical solutions may be used. For surface piercing bodies, results from sink-source methods are to be checked to avoid unreliable predictions in the neighborhood of irregular frequencies. Appropriate computer codes or a compatible procedure acceptable to IRS may be applied. Model tests may be used if the loads cannot be adequately predicted by analytical or computational methods due to the configuration of the structure. In the case of structures consisting of a combination of large and slender parts, diffraction theory and Morrison equation may be respectively used for the appropriate part of the structure. However, modification of the wave particle velocities and accelerations due to the large parts of the structure are to be taken into account in the Morrison equation. Hydrodynamic interactions between large structural members are to be taken into account as applicable.

.11 Increase of wave height near large structures is to be taken into account in the wave load calculations.

.12 For installation sites where the ratio of water depth to wave length is less than 0.25, nonlinear effects of wave action are to be taken into account. This may be done by modifying linear diffraction theory to account for nonlinear effects or by model tests. Shallow water effects are to be considered for the wave load evaluation.

.13 Dynamic wave pressures are to be considered on structural members such as decks and plating which may be impacted by waves.

5.1.3.5 Current Load

.1 Where current is acting alone (i.e., no waves), the drag and lift forces on structural elements at depth z below the still water level is defined as follows:

$$F_{drag,curr} = 0.5\rho C_d A_s u_c^2$$
$$F_{lift,curr} = 0.5\rho C_m A_s u_c^2$$

$F_{drag,curr}$: Drag force per unit length due to current (N)
$F_{lift,curr}$: Lift force per unit length due to current (N)
C_d: Drag Co-efficient
C_m: Lift Co-efficient
u_c: Current Velocity (m/s)
A_s: Project area normal to the current velocity direction (m^2)
ρ: Density of sea water (1025 kg/m^3)

.2 Marine growth where present is to be considered while determining the surface area A_s.

.3 In cases where superposition of current and wave is deemed necessary, the current velocity is to be added vectorially to the wave particle velocity. The resultant velocity is to be used to compute the total force using methods given in 5.1.3.5.1. Apparent wave parameters are to be estimated based on superposition of waves and currents, and used to estimate forces.

.4 Consideration is also to be given to the event of vortex induced vibrations being set up.

5.1.4 Marine Growth

5.1.4.1 Consideration is to be given to the presence of marine growth. The following effects are to be considered as a minimum:

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

Relevant information is to be submitted to IRS for verification.

5.1.4.2 Thickness of marine growth is to be assessed according to local experience. If no relevant data is available, a thickness of 50 mm may be chosen for normal climatic conditions. The thickness of marine growth assumed for the specific design is to reflect the interval and extent of periodic cleaning of submerged members.

5.1.5 Ice Loads

5.1.5.1 The ice loads on the structure due to ice structure interactions are to be taken into account. The local and global effects are to be considered.

5.1.5.2 Ice-structure interactions to be considered for evaluation of loads are to be based on the expected ice environment. The aspects to be included in the evaluation would include ice pressure loads and impact loads from drifting ice and ice bergs.

5.1.5.3 The following aspects of the ice are to be considered in the valuation of ice loads:

a) Ice sheet thickness
b) Ice crystal orientation
c) bulk salinity
d) porosity and density
e) ice strength
f) loading rate
g) temperature
h) Size of structure relative to the ice thickness

5.1.5.4 Annex D of IEC 61400-3-1: 2019 may be referred for further guidance.

5.1.6 Loads from Seismic Events

5.1.6.1 Earthquake and seismic events are to be considered for design of FXOWT which are to be installed in seismically active areas (Refer Section 4.10).

5.1.6.2 Reference is made to API RP 2A, for methods of evaluation for determining structural response to seismic loads.

5.1.7 Support Settlement/Rotation

5.1.7.1 Loads due to support settlement and/ or rotations of the foundations are to be considered. ISO 19902:2020 may be referred for additional guidance.

5.1.8 Actuation Loads

5.1.8.1 Loads due to actuation which may be generated by actuation controls (such as pitch and yaw controller mechanisms, braking loads, generator torque control etc.) are to be considered. The calculation of these loads including the relevant assumptions and conditions is to be clearly documented.

5.1.9 Collision Loads

5.1.9.1 The FXOWT structure is also to consider loads due to accidental impact of service vessel or a drifting vessel. Scenario(s) are to be considered wherein a supply/ service vessel engaged for operations within the wind farm collides with the FXOWT. The integrity of the structures, platforms and ladders including the boat landing is to be ensured against such collisions. For this, the impact energy is to be assessed at an annual probability of exceedance not more than 10^{-4}. The assumptions, rationale and evaluation of collision impact energy is to be properly documented.

5.1.9.2 The maximum permissible significant wave height for vessel operations near the FXOWT is to be stated in the operation manual. Any areas where vessels are not permitted to operate in close proximity are to be specified in the operation manual.

5.1.9.3 Collision on account of a drifting vessel is also to be considered to determine the integrity of the FXOWT. The analysis is to consider the possible ranges of ship sizes transiting in shipping lanes in proximity which are relevant to the event of drifting collision.

5.1.9.4 IEC 61400-3-1:2019 may also be referred for further guidance on evaluation of collision loads.

5.1.10 Loads from Helicopter Operations

5.1.10.1 Where applicable, loads from helicopter operations are to be evaluated. Impact due to helicopter accident is to be considered. The ambient environment conditions are to be considered as the combination of most severe wind and sea conditions wherein the helicopter operations are permitted. The rationale, assumptions and the evaluation of these loads is to be documented.

5.1.11 Loads from Dropped Objects

5.1.11.1 Where applicable, loads from dropped objects are to be considered. For this purpose, lifting operations which may lead to dropped object loads are to be identified. The dropped object loads are to be evaluated at an annual probability of exceedance not more than 10^{-4}.

5.2 Load Combinations

5.2.1 Load Cases

5.2.1.1 Various loads to be considered during the design of the FXOWT are detailed in Section 4.

5.2.1.2 The minimum number of Load Cases to be considered for analysis are shown in Table 5.2.1.2. These load cases are generally in accordance with those given in IEC 61400-3-1:2019. Other load cases may need to be considered as deemed relevant to assess the adequacy of the support structure.

5.2.1.3 The minimum number of Load Cases to be considered for FXOWTs exposed to sea ice conditions is shown in Table 5.2.1.3. These load cases are in accordance with those as given in IEC 61400-3-1:2019.

5.2.1.4 DLC 1.1 from IEC 61400-3-1 is not to be considered since the RNA is not included within the scope of Classification.

5.2.1.5 The return period for the combination of environmental conditions such as waves, current etc. is not to be less than 50 years. This is valid for DLC 1.6, 6.2 and 6.2. For sites which may be frequently exposed to tropical cyclones such return period is to be considered as 100 years unless it can be justified otherwise.

5.2.1.6 Where a range for wind speed is indicated in Table 5.2.1.2, the wind speeds which produce the most severe response are to be considered for analysis. For practical purpose, it is recommended that wind speeds may be considered to be represented by a set of discrete values which are spaced by an interval not exceeding 2 m/s.

5.2.1.7 For time history based analyses (time domain simulations), the duration of the analyses considering combinations of wind, wave is to be appropriately selected so that as to obtain a realistic estimate of the extreme response of the structure. Selection of such time durations have to be accompanied with a sound technical justification.

5.2.1.8 Static loads (e.g gravity loads, hydrostatic pressure, soil pressure etc.) and live loads are to be combined with the dynamic load cases as shown in the Tables 5.2.1.2 and 5.2.1.3.

5.2.1.9 Further guidance regarding analysis of load cases and the number of simulations to be performed is given in Sections 7.4 and 7.5.6 of IEC 61400-3-1:2019.

5.3 Structural Analysis

5.3.1 Analysis Programs and Techniques

5.3.1.1 Structural analysis is to be performed for the loads and load combination as highlighted in Sections 5.1 and 5.2 respectively.

5.3.1.2 Computer Programs acceptable to IRS are to be used for performing the structural analyses.

5.3.1.3 Suitable modeling techniques are to be utilized to properly model the structural stiffness and inertia.

5.3.1.4 Suitable analysis techniques are to be selected for determining the response of the structure. In general, use of dynamic analysis with time history based simulations is recommended to accurately calculate the responses. Effects on stiffness due to large deformations/deflections is also to be accounted for.

5.3.1.5 The analyses are to take into account the interaction of the foundation with the surrounding soil, i.e. soil-structure interaction.

5.3.1.6 Where concrete structures are utilized, analysis is to take into account the in-elastic behavior of concrete. Utilization of plastic methods of design are to be only considered for the ultimate limit states and occurrence of seismic loads.

5.3.1.7 The effect of imperfections & construction tolerances is to be considered when checking the structural instability failure mode.

Table 5.2.1.2: Design Load Combinations

Scenario	DLC	Wind Condition	Wave	Wind and Wave Directionality	Sea Current	Water Level	Type of Analysis	Additional Notes	Partial Safety Factor (See Table 5.4.2.2)
1) Power Generation	1.2	NTM $V_{in}<V_{hub}<V_{out}$	NSS Joint probability distribution of H_s, T_p and V_{hub}	MIS, MUL	No Currents	NWLR or ≥ MSL	FLS		
	1.3	ETM $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS		N
	1.4	ECD $V_{hub}=V_R-2$, V_R, V_R+2 (m/s)	NSS $H_S=E[H_s/V_{hub}]$	MIS, Wind Direction change	NCM	MSL	ULS		N
	1.5	EWS $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS		N
	1.6	NTM $V_{in}<V_{hub}<V_{out}$	SSS $H_S=H_{S,SSS}$	COD, UNI	NCM	NWLR	ULS		N
2) Power Generation with Fault Occurrence	2.1	NTM $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS	Normal control system fault or loss of electrical network or primary layer control function fault	N
	2.2	NTM $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS	Abnormal control system fault or secondary layer protection function related fault	A

	2.3	EOG $V_{hub}=V_R\pm2$, V_{out} (m/s)	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS	External or internal electrical fault including loss of electrical network	A
	2.4	NTM $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	No Currents	NWLR or ≥ MSL	FLS	Control system fault, electrical fault or loss of electrical network	
	2.5	NWP $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS	Low voltage ride through	N
3) Start Up	3.1	NWP $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	No Currents	NWLR or ≥ MSL	FLS		
	3.2	EOG $V_{hub}=V_{in}$, $V_R\pm2$, V_{out} (m/s)	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS		N
	3.3	EDC $V_{hub}=$ V_{in}, $V_R\pm2$, V_{out} (m/s)	NSS $H_S=E[H_s/V_{hub}]$	MIS, Wind Direction Change	NCM	MSL	ULS		N
4) Normal Shutdown	4.1	NWP $V_{in}<V_{hub}<V_{out}$	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	No Currents	NWLR or ≥ MSL	FLS		
	4.2	EOG $V_{hub}=V_R\pm2$, V_{out} (m/s)	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS		N
5) Emergency Stop	5.1	NTM $V_{hub}=V_R\pm2$, V_{out} (m/s)	NSS $H_S=E[H_s/V_{hub}]$	COD, UNI	NCM	MSL	ULS		N
6) Parked Condition	6.1	EWM Turbulent Wind Model $V_{hub}=V_{ref}$	ESS $H_s=H_{s,50}$	MIS, MUL	ECM $U=U_{50}$	EWLR	ULS		N
	6.2	EWM Turbulent Wind Model $V_{hub}=V_{ref}$	ESS $H_s=H_{s,50}$	MIS, MUL	ECM $U=U_{50}$	EWLR	ULS	Loss of Electrical Network	A

	6.3	EWM Turbulent Wind Model $V_{hub}=V_1$	ESS $H_s=H_{s,1}$	MIS, MUL	ECM $U=U_1$	NWLR	ULS	Extreme Yaw Misalignment	N
	6.4	NTM $V_{out}<V_{hub}<0.7V_{ref}$	NSS Joint probability distribution of H_s, T_p, V_{hub}	COD, MUL	No Currents	NWLR or ≥ MSL	FLS		
7) Parked and Fault	7.1	EWM $V_{hub}=V_1$	ESS $H_s=H_{s,1}$	MIS, MUL	ECM $U=U_1$	NWLR	ULS		A
	7.2	NTM $V_{hub}<V_{out}$	NSS Joint probability distribution of H_s, T_p, V_{hub}	COD, MUL	No Currents	NWLR or ≥ MSL	FLS		
8)Transit, Maintenance, Repair	8.1	To be defined by the designer					ULS		N
	8.2	EWM $V_{hub}=V_1$	ESS $H_s=H_{s,1}$	COD, UNI	ECM $U=U_1$	NWLR	ULS		A
	8.3	NTM $V_{hub}<0.7V_{ref}$	NSS Joint probability distribution of H_s, T_p, V_{hub}	COD, MUL	No Currents	NWLR or ≥ MSL	FLS	No grid during installation period	
	8.4	To be defined by the designer					FLS		
COD		Co-Directional							
MIS		Misaligned							
MUL		Multidirectional							
$H_{s,1}$		Significant Wave Height with Return Period of 1 year							
$H_{s,50}$		Significant Wave Height with Return Period of 50 years							
U_1		Current Velocity with Return Period of 1 year							
U_{50}		Current Velocity with Return Period of 50 years							
V_{ref}		extreme 10 min average wind speed with a recurrence period of 50 years at turbine hub height							
V_1		Expected extreme wind speed averaged over 10 minutes with return period of 1 year							
$V_R±2$		Sensitivity to all wind speeds in the range to be analysed							

Table 5.2.1.3: Design Load Cases for Sea Ice						
Scenario	**DLC**	**Ice Condition**	**Wind Condition**	**Water Level**	**Type of Analysis**	**Partial Safety factor (See Table 5.4.2.2)**
Power Generation	D1	Horizontal Load from temperature fluctuations	NTM $V_{hub}=V_R\pm2$, V_{out} (m/s), Wind speed resulting in maximum thrust	NWLR	ULS	N
	D2	Horizontal Load from water level fluctuations or arch effects	NTM $V_{hub}=V_R\pm2$, V_{out} (m/s), Wind speed resulting in maximum thrust	NWLR	ULS	N
	D3	Horizontal Load from moving ice at relevant velocities, $h=h_{50}$ or largest value of moving ice	NTM $V_{in}<V_{hub}<V_{out}$	NWLR	ULS	N
	D4	Horizontal Load from moving ice at relevant velocities Use of values of h corresponding to expected history of moving ice	NTM $V_{in}<V_{hub}<V_{out}$	NWLR	FLS	
	D5	Vertical force from fast ice covers due to water level fluctuations	No Wind Load Applied	NWLR	ULS	N
Parked	D6	Pressure from hummocked ice and ice ridges	EWM Turbulent Wind Model $V_{hub}=V_1$	NWLR	ULS	N
	D7	Horizontal Load from moving ice at relevant velocities Use of values of h corresponding to expected history of moving ice	NTM $V_{hub}<0.7V_{Ref}$	NWLR	FLS	
	D8	Horizontal Load from moving ice at relevant velocities, $h=h_{50}$ or largest value of moving ice	EWM Turbulent wind model $V_{hub}=V_1$	NWLR	ULS	N
h_1: Thickness of ice with return period of 1 year (m) h_{50}: Thickness of ice with return period of 50 years (m) Definition of other terms in the table may be referred from Table 5.2.1.2						

5.3.1.8 The simultaneous nature of the various loads is to be accounted for and cumulative structural response is to be determined using appropriate techniques. The assumptions utilized in the analysis are to be clearly documented.

5.3.1.9 Natural frequencies of the support structure are to be determined and reported. For this purpose, the tower and the foundation are also to be considered along with the supporting structure. Natural frequencies evaluation is to taken into account possibility of scour, support settlement, corrosion and marine growth during the design life of the structure. Damping mechanisms from aerodynamic, hydrodynamic, structural and soil are to be considered when determining the natural frequencies.

5.3.1.10 Excitation frequencies on the structure arising from the RNA and its components are to be determined. Likewise, the range of excitation frequencies from waves are to be determined and documented.

5.4 Design Requirements

5.4.1 Common Design Requirements

5.4.1.1 Air Gap

5.4.1.1.1 A minimum air gap is to be maintained at all times above the highest sea water level and the lowest edge of the supporting structure which is not designed for wave impact forces. The minimum air gap is not to be less than 1.5 m

5.4.1.1.2 The long term settlement and rotation of the supporting structure is to be considered when evaluating the minimum air gap.

5.4.1.1.3 For sites which are subject to frequent cyclonic conditions, the minimum air gap as specified above will be specially considered by IRS.

5.4.1.2 Fatigue Life

5.4.1.2.1 The design life of the FXOWT is not to be less than 20 years.

5.4.1.3 Corrosion Protection for Steel

5.4.1.3.1 An appropriate Corrosion Protection system for steel structures is to be provided.

5.4.1.4 Scour Protection System

5.4.1.4.1 For sites susceptible to scouring, a scour protection system is to be provided unless the design of the FXOWT takes into account the effect of scouring.

5.4.2 Steel Structures Design

5.4.2.1 LRFD method of structural design is to be used for design of structural members.

5.4.2.2 The partial safety factors as shown in Table 5.4.2.2 are to be used for application to dynamic environmental loads such as aerodynamic loads, hydrodynamic loads, current loads etc. and concurrently in accordance with Table.5.4.2.2

Table 5.4.2.2: Safety Factors		
Normal (N)	**Abnormal (A)**	**Transport Assembly Maintenance Repair (T)**
1.35	1.1	1.5

5.4.2.3 For static loads such as gravity loads, live loads, hydrostatic loads etc. a partial safety factor of 1.0 is to be used.

5.4.2.4 Partial Safety Factors are to be applied to the dynamic loads and combined with the static loads.

5.4.2.5 Design of Tubular structural members is to be in accordance with API RP 2A – LRFD approach. The member structural capacities and resistances are to be determined in accordance with the above mentioned standard. For non-tubular structural member AISC code is to be used for determination of member structural capacities and resistances.

5.4.2.6 Design of local structural details is to be in accordance with API RP 2A.

5.4.3 Concrete Structures Design

5.4.3.1 Structural Design

.1 LRFD method of structural design is to be used for design of structural members. In general, the design of structural members is to be in accordance with ACI 357R.

.2 The partial safety factors as shown in Table 4.2.2 are to be used for application to dynamic environmental loads such as aerodynamic loads, hydrodynamic loads, current loads etc and concurrently in accordance with Table.

.3 For static loads such as gravity loads, live loads, hydrostatic loads, etc. a partial safety factor of 1.0 is to be used.

.4 Partial Safety Factors are to be applied to the dynamic loads and combined with the static loads.

.5 The following modes of structural failure should be considered from the structural strength point of view:

a) Loss of overall equilibrium
b) Failure of critical sections
c) Instability resulting from large deformations
d) Excessive creep or plastic deformation.

.6 The following modes of structural failure should be considered from the serviceability point of view:

a) Excessive Cracking

b) Unacceptable deformations
c) Corrosion of reinforcement and deterioration of concrete
d) Vibrations
e) Excess leakage

.7 Strength reduction factors for various resistance actions are to be taken in accordance with ACI 357R.

.8 Control of cracking based upon limiting stresses within the reinforcement members is recommended as provided in Table 4.1 of ACI 357R.

.9 Strength reduction factors for various effects (shear, bending, axial resistance etc.) are to be considered in accordance ACI 357R.

.10 Minimum reinforcement is to be provided within concrete structural members in accordance with ACI 357R.

.11 Member Structural Capacities and Resistance are to be evaluated in accordance with ACI 357R and ACI 318 as appropriate.

5.4.3.2 Materials and Durability

.1 The requirements as provided in ACI 357R are to be complied with.

5.4.4 Foundation Design

5.4.4.1 Pile Foundations

.1 The design of pile foundations is to be in accordance with Chapter 7, Section 4 of the *Rules and Regulations for the Construction and Classification of Fixed Offshore Steel Structures*. Pile foundations (associated with fixed steel structures) designed in accordance with recognized standards such as ISO 19902:2020 may also be accepted by IRS.

5.4.4.2 Shallow Foundations

.1 The design of shallow foundations is to be in accordance with ISO 19901-4:2016. IRS may accept shallow foundations designed in accordance with other recognized standards provided they contain requirements no less stringent than those in the above mentioned standard.

5.4.4.3 Gravity Base Foundations

.1 Foundations consisting of gravity base structures associated with concrete, are to be in accordance with ISO 19903:2019.

Section 6

Safety Systems and Equipment

6.1 General

6.1.1 Hazards on the FXOWT should be determined considering its operations as well as the external conditions. The FXOWT may be considered to be an installation which is normally unmanned for this purpose. The report determining such hazards should be submitted to IRS for information and reference.

6.1.2 If there is risk of icing at site, then limitation of accessibility to ladders and platforms under icing conditions should be considered. Risk of damage to structures from ice should be considered.

6.1.3 Adequate clearance between rotating blade tip and walkways/ platforms should be catered for in the design.

6.1.4 Precautions to be taken by personnel entering enclosed spaces such as hub or blade interiors, and role of standby personnel should be included in the operation and maintenance manual.

6.1.5 Safety Regulations of the statutory authorities are also to be complied with.

6.1.6 Plans, drawings and reports of the items as described in the present section should be submitted for review of IRS.

6.2 Safety Systems and Equipment

6.2.1 Hazards pertaining to fire safety should be addressed by suitable provisions of combination of passive fire protection and active firefighting equipment. The selected equipment should be appropriate to fight the particular type of the fire, readily accessible and in state of operational readiness.

6.2.2 Other safety systems, equipment and arrangements should be suitably designed and installed to prevent and/or mitigate hazards identified as outlined in 6.1.1. Such systems and equipment typically may include the following but not be limited to:

a) Illumination system
b) External illumination (to prevent accidental ship collisions or helicopter accident)
c) Remote startup/ shutdown systems

6.3 Personnel Safety

6.3.1 Personnel safety aspects should be provided as below:

a) Climbing facilities
b) Accessways and passages
c) Standing places, platforms and doors
d) Hand rails and fixture points
e) Adequate Lighting
f) Electrical and earthing system
g) Emergency stop buttons

h) Provision of alternative escape routes
i) Provisions for emergency stay in the FXOWT for one week
j) Offshore specific safety equipment for the Offshore Wind Turbine

End of the Guidelines