GUIDELINE

NKRE-GL-WFC01

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ClassNK

NIPPON KAIJI KYOKAI

Wind Farm Certification

Onshore Wind Power Plant Edition

RENEWABLE ENERGY

Revision History

I. July 30, 2021 New issue (Document No.: NKRE-GL-WFC01, Edition: July 2021)

* Correction of error and Minor change have applied on 1st October 2021 (No change of Document No.)

EFFECTIVE DATE and APPLICATION

1. These guidelines shall be enforced from August 1, 2021.
2. Notwithstanding the provisions of these guidelines, the provisions then in force shall remain applicable to power plants other than those falling under any of the following.
   (1) Power plants for which the application for examination pertaining to wind farm certification is accepted on or after January 1, 2022.
   (2) Power plants for which the initial certification document of wind farm certification is issued on or after May 1, 2022

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Chapter 1 General

1.1 General

1.1.1 Application

-1. These guidelines specify the requirements for onshore wind power plants that are subject to wind farm certification.

-2. The requirements specified in these guidelines apply to the case where the wind turbine is a propeller type horizontal shaft with three blades and is supported by a monopole tower that is cylindrical (including conical) and made of steel.

-3. It should be noted that if there is a change in the requirements for the construction plan examination based on the Electricity Business Act, those requirements shall take precedence over the provisions of these guidelines.

1.1.2 Wind power generation facilities with a new concept

-1. For wind power plants that have a different type or facilities from those specified in these guidelines, the requirement determination and evaluation may be implemented individually in accordance with the basic principles behind the provisions of these guidelines.

1.1.3 Design life and service life

-1. The design life and service life in these guidelines shall both be 20 years.

-2. If the design life or service life are to be different from those in -1 above, the requirement determination and evaluation shall be implemented individually in accordance with the basic way of thinking behind the provisions of these guidelines.

1.2 Normative References

1.2.1 General

-1. The following standards are the normative references for wind farm certification that are specified in the "Sector-specific guidelines for ‘accreditation criteria’ - Wind power generation systems: wind farms, projects -" (JAB PD366:2017) document produced by the Japan Accreditation Board, excluding those for offshore and small wind turbines. Where an anno domini year is written for these cited standards, the version of the year mentioned shall apply, and subsequent revised versions (including Supplements) shall not apply. If there is no anno domini year written for a normative references, the most recent version (including Supplements) shall apply.

[J-01] JIS C 1400-1:2017 : Wind Energy Generation Systems-Part 1: Design requirements
[J-02] IEC 61400-1 2019 : Wind energy generation systems - Part 1: Design requirements
[J-03] Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities (Ministry of Economy, Trade and Industry, Ordinance of the Ministry of International Trade and Industry No. 53 of March 27, 1997, final revision: Ordinance of the Ministry of Economy, Trade and Industry No. 32 of March 31, 2017)
[J-04] Interpretation of Technical Standards for Wind Power Generation Facilities (Ministry of Economy, Trade and Industry, No. 20140328, Bureau of Commerce No. 1, April 1, 2014)
[J-05] Guidelines for Design of Wind Turbine Support Structures and Foundation [2010 version] (Japan Society of Civil Engineers)
[J-06] Germanischer Lloyd (GL) Guideline for the Certification of Wind Turbines 2010

-2. In order to meet the requirements of the standards listed in -1 above, the following standards referenced by these guidelines shall form part of the provisions. Where an anno domini year is written for these cited standards, the version of the year mentioned shall apply, and subsequent revised versions (including Supplements) shall not apply. If there is no anno domini year written for a cited standard, the most recent version (including Supplements) shall apply.

[R-01] NKRE-SP-0003 Wind Farm Certification Procedures, Edition February 2021
[R-02] Annotations to the Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities and its Interpretation (Ministry of Economy, Trade and Industry, revised on June 21, 2021)

[R-03] Implementation procedures for the examination of construction plans for the installation or modification of wind power plants (Ministry of Economy, Trade and Industry, No.20210518, Bureau No. 1, May 24, 2021)
[R-04] Recommendations for Design of Building Foundations (Architectural Institute of Japan, 2019)
[R-05] Guidebook on Design and Fabrication of High Strength Bolted Connections (Architectural Institute of Japan, 2003)
[R-06] Structural Design Recommendation for Chimneys (Architectural Institute of Japan, 2007)
[R-07] JIS C 1400-12-1:2010 : Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines
[R-08] JIS C 1400-24:2014 : Wind turbines - Part 24: Lightning protection
[R-09] IEC 61400-6:2020 : Wind energy generation systems - Part 6: Tower and foundation design requirements
[R-10] IEC 61400-13:2015 : Wind turbines - Part 13: Measurement of mechanical loads
[R-11] ISO 273:1979 : Fasteners - Clearance holes for bolts and screws
[R-12] ISO 4354:2009 : Wind actions on structures
[R-13] EN 1993-1-9:2005 : Design of steel structures - Part 1-9: Fatigue
[R-14] fib Model Code for Concrete Structures 2010(CEB-FIP Model Code 2010)
[R-15] CEB-FIP Model Code 1990
[R-16] DNVGL-ST-0126 Support structures for wind turbines, Edition April 2016
[R-17] MEASNET Evaluation of Site-Specific Wind Conditions, Version 2, April 2016
[R-18] IEC 61400-12-1:2017 : Wind energy generation system - Part 12-1: Power performance measurements of electricity producing wind turbines

1.3 Definitions and abbreviations

1.3.1 Definition of terms

-1. The definitions of the key terms used in these guidelines are given in Table 1-1.

Table 1-1 Definition of terms

Term	Definition
Requester	A person who submits an application for examination pertaining to wind farm certification.
NK-PASS	The document submission and management system available on the ClassNK website.
Environmental conditions	Characteristics such as wind, altitude, temperature, humidity, and atmospheric pressure which may affect the behavior of the wind turbine.
External conditions	Factors affecting wind turbine operation, including the environmental conditions, the ground and geological conditions, and the power system conditions.
Annual average	A value that is obtained by averaging measurement data sets containing enough data collected over a sufficient period, and is capable of estimating the expected value of an item to be measured. It is desirable that the period for calculating the average is an integer multiple of one year unit, in order to smooth out unsteady effects such as seasonal differences.
Average wind speed	The statistical average of the instantaneous values of wind speed averaged over a given period varying from seconds to years.
Annual average wind speed	The wind speed averaged in accordance with the definition of the annual average.
Hub height	The height from the ground of the center of the wind receiving surface of the wind turbine rotor (the center of the plane projected perpendicular to the wind direction during one rotation).
Cut-in wind speed	The minimum wind speed at the hub height at which the wind turbine begins to generate power in the case of steady wind without turbulence.
Cut-out wind speed	The maximum wind speed at the hub height at which the wind turbine is designed to generate power in the case of steady wind without turbulence.
Rated output	The value of the output normally obtained when the components, equipment and facilities specified by the manufacturer are operated under the specified conditions. In the case of wind turbines, this is the maximum continuous output (of the wind turbine) designed to be supplied under normal operating conditions and external conditions.

Term	Definition
Rated wind speed	The minimum wind speed at the hub height at which the wind turbine reaches the rated output in the case of steady wind without turbulence.
Reference wind speed (V_{ref})	The wind speed at hub height used to define the wind turbine class in JIS C 1400-1: 2017 [J-01], which is set as the 10 minutes average wind speed with a return period of 50 years.
Reference wind speed (V_0)	According to the Building Standards Act, this is the 10 minutes average wind speed with a return period of 50 years at a height of 10 m that is specified by the Minister of Land, Infrastructure, Transport and Tourism. It is specified within a range from 30 m/s to 46 m/s according to the degree of wind damage and other wind characteristics in the area based on the records of past typhoons, etc.
Extreme wind speed	The average wind speed corresponding to a return period of 50 year.
During power production	The state in which a wind turbine is operating for power generation between the cut-in wind speed and the cut-out wind speed.
During parked by storm	The state when the wind speed exceeds the cut-out wind speed and the wind turbine stops the power generation and enters a standby state.
Complex terrain	Surrounding terrain where the airflow is easily distorted due to the terrain having many variations or the presence of obstacles.
Roughness	The roughness and smoothness of the boundary such as surface roughness, trees and buildings.
Roughness length	The extrapolated height at which the average wind speed becomes zero when the vertical wind speed profile is assumed to change logarithmically with height.
Ground surface roughness classification	A classification of the ground surface in stages from a smooth state to a rough state.
Turbulence intensity	The standard deviation of the fluctuating wind speed divided by the average wind speed.
Turbulence standard deviation	The standard deviation of the principal direction component of the turbulence wind speed at hub height.
Wind condition measurement data	Time series data of the 10 minute average value for wind speed, wind speed standard deviation, and wind direction for at least one continuous year.
Effective data rate	The data sufficiency rate after filtering processing is conducted on the wind condition measurement data to remove abnormal values, etc., or after data filling is conducted on the wind measurement data.
Data sufficiency rate	The value obtained by dividing "the number of 10 minute averages that can be used after filtering" by "the total number of 10 minute averages corresponding to the measurement period" during the relevant measurement period.
Correlation coefficient	An indicator that measures the strength of the linear relationship between two data or random variables.
Coefficient of determination	The value which indicates the extent to which an independent variable contributes to a dependent variable. It is a measure of the applicability of the regression equation obtained from the sample value.
Airflow analysis	A numerical analysis that calculates the flow of air.
Airflow analysis model	The equations applied to airflow analysis and their solutions. (A linear model is applied in cases where flat terrain stretches over a vast area, such as in parts of Europe. However, a nonlinear model is suitable in cases where the terrain has large slope gradients, such as in Japan.)
Ambient turbulence standard deviation	The standard deviation of the main direction component of the wind speed at the wind turbine position and hub height as predicted and calculated from the results of airflow analysis using measurement data. (It is usually calculated per wind speed bin.)
Ambient turbulence intensity	The value obtained by dividing the ambient turbulence standard deviation by the wind speed.
Wind turbine wake effect	When neighboring wind turbines experience disturbance due to the wind (wake) that has passed the rotor plane of the wind turbine.
Effective turbulence intensity	The value obtained by adding the turbulence intensity due to the wake effect from wind turbines to the ambient turbulence intensity.
Wind shear	A mathematical representation that is assumed for the change in wind speed relative to the height above ground level.
Wind shear exponent	The index of the power law for wind shear.
Flow inclination angle	The inclination angle of the inflow wind relative to the rotor plane at hub height.

Term	Definition
Power back-up	A power supply system that supplies power to operate the wind turbine control system in the event of a loss of electrical power network loss.
Yaw control	Control to make the wind turbine nacelle direction angle (angle of the rotor shaft) follow the changes in the wind direction.
Yaw misalignment	The error between the nacelle direction angle (angle of the rotor shaft) and the wind direction, generally shown as a 10 minute average value.
Wind force coefficient	The aerodynamic force acting on a structure divided by the product of the velocity pressure and the representative area. The average wind force coefficient means the time average.

1.3.2 Definition of abbreviations

-1. The definitions of the main abbreviations used in these guidelines are given in Table 1-2.

Table 1-2 Definition of abbreviations

Abbreviations	Definition
RNA	Rotor Nacelle Assembly
DLC	Design Load Case
MCP	Measure-Correlate-Predict

1.3.3 Meaning and units of symbols

-1. The meanings and units of the main symbols used in these guidelines are specified in Table 1-3.

Table 1-3 Definition of symbols

Symbol	Meaning	Units
C_{CT}	Turbulent structure intensity parameter (See JIS C 1400-1:2017 [J-01] 11.2)	
D	Rotor diameter	
I_{ref}	Expected value hub height turbulence intensity at a 10 minute average wind speed of 15 m/s [J-01] Reference value of the turbulence intensity corresponding to the 70% quantile at 15 m/s [J-02]	
I_{rep}	90% quantile of the ambient turbulence intensity	
I_{eff}	Effective turbulence intensity	
V_{hub}	Wind speed at hub height	$[m/s]$
V_{ave}	Annual average wind speed	$[m/s]$
V_{in}	Cut-in wind speed	$[m/s]$
V_{out}	Cut-out wind speed	$[m/s]$
V_r	Rated wind speed	$[m/s]$
V_{ref}	Reference wind speed (JIS C 1400-1:2017 [J-01])	$[m/s]$
V_0	Reference wind speed (Building Standards Act)	$[m/s]$
$\hat{\sigma}$	Estimated wind speed standard deviation	$[m/s]$
$\hat{\sigma}_\sigma$	Standard deviation of estimated wind speed standard deviation $\hat{\sigma}$	$[m/s]$
$\hat{\sigma}_1$	Hub height longitudinal wind velocity standard deviation at wind turbine position	$[m/s]$
$\hat{\sigma}_2$	Hub height lateral wind velocity standard deviation at wind turbine position	$[m/s]$
$\hat{\sigma}_3$	Hub height upward wind velocity standard deviation at wind turbine position	$[m/s]$
U_h	Hub height 10 minutes average wind speed with a return period of 50 years at wind turbine position	$[m/s]$
U_{e50}	Hub height 3 seconds average wind speed with a return period of 50 years at wind turbine position	$[m/s]$
I_{h1}	Hub height turbulence intensity for 10 minutes average wind speed with a return period of 50 years at wind turbine position.	

1.4 Wind farm certification

1.4.1 General

-1. Wind farm certification is a procedure whereby ClassNK issues a document to certify that one or more wind turbines (RNA) and their support structures (towers and foundations) meet the requirements for a particular site.

-2. In principle, the wind farm certification is for wind power plants in Japan that have an output of 500 kilowatts or more, where one or more wind turbines (RNA) and their support structures (towers and foundations) are installed and are subject to the Electricity Business Act. Cases where the project is not in Japan shall be handled separately as judged appropriate by ClassNK.

-3. The purpose of wind farm certification is to assess whether type-certified wind turbines (RNA) and towers, and the design of foundations are in conformity with the external conditions and the requirements under the Electricity Business Act.

-4. In principle, wind farm certification is not permitted for power plants that use wind turbines (RNA) or towers that have not obtained type certification. However, in the case of a wind turbine which has acquired a design evaluation conformity statement and is carrying out type testing for the acquisition of type certification, the wind farm certification may be issued on the condition that the acquisition of the type certification is set as an outstanding issue and a time limit for the solution of that outstanding issue is established.

-5. Procedures related to wind farm certification which are not described in these guidelines shall follow the Wind Farm Certification Procedures [R-01].

1.4.2 Evaluation module

-1. In principle, wind farm certification shall consist of the following modules. The relationships between individual modules are shown in Figure 1-1.

(1) Site conditions assessment
(2) Design basis evaluation
(3) Integrated load analysis
(4) Wind turbine (RNA) design evaluation
(5) Support structure design evaluation

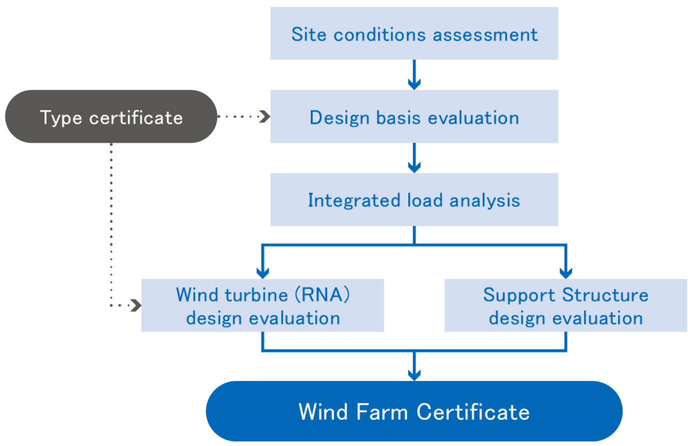

Figure 1-1 Module for wind farm certification

1.4.3 Site conditions assessment

-1. The site conditions assessment evaluates whether the external conditions have been set appropriately based on the results of field measurements, field investigations, etc. The details of the assessment are given in Chapter 2.

1.4.4 Design basis evaluation

-1. The design basis evaluation evaluates whether the design basis has been properly documented and is sufficient for safe design and power plant construction. The details of the evaluation are given in Chapter 3.

1.4.5 Integrated load analysis evaluation

-1. The integrated load analysis evaluation evaluates whether the site-specific loads and load effects on the integrated wind turbine, which includes the wind turbine (RNA), the support structure and supporting ground, have been calculated in conformity with the design basis. The details of the evaluation are given in Chapter 4.

1.4.6 Wind turbine (RNA) design evaluation

-1. The wind turbine (RNA) design evaluation evaluates whether the design of the wind turbine (RNA) is in conformity with the site-specific conditions and design basis. The details of the evaluation are given in Chapter 5.

1.4.7 Support structure design evaluation

-1. The support structure design evaluation evaluates whether the design of the support structure (tower and foundation) is in conformity with the site-specific conditions and design basis. The details of the evaluation are given in Chapter 6.

1.4.8 Wind farm certification module for onshore wind power plants

-1. In the case of an onshore wind power plant, the certification may consist of the following modules [M1] to [M4], regardless of the provisions of 1.4.2. The relationships between the modules in this case are shown in Figure 1-2. In addition, the contents of the evaluations which constitute each module shall follow 1.4.3 to 1.4.7.

[M1] Site conditions assessment (Wind conditions)
[M2] Wind turbine (RNA) design evaluation (including site conditions assessment, design basis evaluation and integrated wind load analysis)
[M3] Support structure design evaluation (Tower) (including site conditions assessment, design basis evaluation and integrated load analysis)
[M4] Support structure design evaluation (Foundation) (including site conditions assessment, design basis evaluation and integrated load analysis)

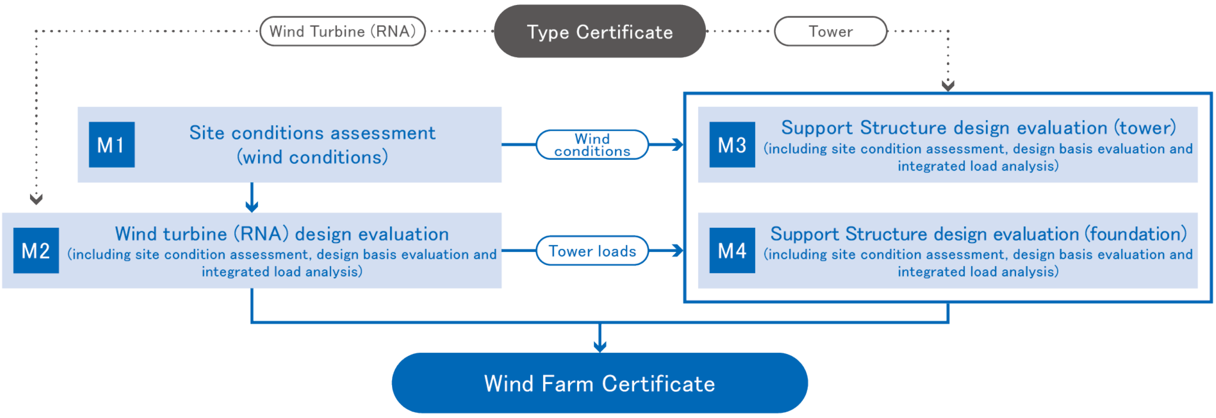

Figure 1-2 Wind farm certification module [Limited to onshore wind power plants]

1.4.9 Certification subcommittees

-1. The certification subcommittees shown in Table 1-4 shall be held according to the items to be examined.

-2. In principle, the format when the Large Wind Turbine Certification Subcommittee and the Support Structure Certification Subcommittee Tower Section Meeting are held shall be that the ClassNK secretariat explains the evaluation results to the subcommittee/section meeting members.

-3. In addition to -2. above, in cases where the requirements for general facilities do not apply as a result of the Implementation procedures for the examination of construction plans for the installation or modification of wind power plants [R-02], after the examination by ClassNK is completed, a place may be established where the requester directly explains the content of the construction plan to the subcommittee/section meeting members based on the results of the examination by ClassNK. The only language accepted for the materials used for explanation in the relevant subcommittee/section meeting shall be Japanese.

-4. In principle, the format when the Support Structure Certification Subcommittee Foundation and Ground Section Meeting is held shall be that the requester directly explains the contents related to the items to be examined to the members of the section meeting. The only language accepted for the materials used for explanation in the relevant section meeting shall be Japanese.

Table 1-4 Certification subcommittees

Certification subcommittee	Items to be examined
Large Wind Turbine Certification Subcommittee	[M1] Site conditions assessment (Wind conditions) [M2] Wind turbine (RNA) design evaluation (including site conditions assessment, design basis evaluation and integrated wind load analysis)
Support Structure Certification Subcommittee Tower Section Meeting	[M3] The Support structure design evaluation (Tower) [including site conditions assessment, design basis evaluation and integrated load analysis] items that deviate from the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]
Support Structure Certification Subcommittee Foundation and Ground Section Meeting	[M4] The Support structure design evaluation (Foundation) [including site conditions assessment, design basis evaluation and integrated load analysis] items that deviate from the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]

1.5 Documents to be submitted

1.5.1 General

-1. In order to be examined for wind farm certification, the requester shall submit to ClassNK the documents listed in 1.5.2 to 1.5.6 in accordance with the items to be evaluated. In addition to these documents, the requester shall provide sufficient and accurate information (documents, records, etc.) deemed necessary by ClassNK.

-2. The materials to be submitted to ClassNK shall satisfy the following conditions.

- The responsibility for the preparation or issuing of materials shall be clarified.
- The item has a document number.
- The date of issue is clear.
- The history (revision history) is written, and in addition to the revision date and the document number after the revision, the parts that have been revised and the contents of the revision are clear.
- In principle, the language of materials to be submitted shall be Japanese. However, English may be used if ClassNK deems it appropriate. Other languages are not permitted.
- In principle, the SI unit system shall be used as the units in the documents to be submitted.

-3. In principle, NK-PASS shall be used to submit the documents requested by ClassNK.

1.5.2 Materials related to wind turbine type certification

-1. In the examination for the wind farm certification, the design conditions in the wind turbine type certification become the basis, so in order to check the details, the documents listed below that have been issued by the certification organization concerning the type certification must be submitted to ClassNK.

(1) Type certificate and final evaluation report
(2) Design basis evaluation conformity statement and its evaluation report
(3) Design evaluation conformity statement and its evaluation report
(4) Type testing conformity statement and its evaluation report
(5) Manufacturing evaluation conformity statement and its evaluation report
(6) Component certificate and its evaluation report

-2. Class NK will designate submittal documents those the drawings and calculation materials which shall be submitted from the wind turbine manufacturer to the type certification body and referenced in the evaluation reports in (1) to (6), according to each wind turbine type.

1.5.3 Materials related to the site conditions assessment (wind conditions)

-1. The following documents and data shall be submitted to ClassNK as examination materials related to the site conditions assessment. The documents may be in a format that combines the following items.

(1) Report regarding basic information on the planned site
*The following information shall be included.
- Site location
- Type of wind turbine to be used and number of wind turbines
- Wind turbine layout
- Wind turbine coordinates (World Geodetic System: WGS 84 and UTM)
- Plan for wind turbine operation at the site (Cut-in and cut-out wind speeds, rated output, rated wind speed, power curve, etc.)

(2) Report on field measurements (to include the items listed in Annex A.5)
(3) Report on wind conditions during power production (to include the items listed in Annexes B.3.1 and C.4.1)
(4) Report on wind conditions during parked by storm (to include the items listed in Annexes B.3.2 and C.4.2)
(5) Report on storm duration (Only when the power back-up specified in 5.4.2 is installed)

-2. The following data shall be submitted to ClassNK when deemed necessary by ClassNK for the examination related to the site conditions assessment (wind conditions).

(1) Field measurement data (Time series data of 10 minute average value corresponding to the measurement period applied to airflow analysis)
(2) Results data from CFD analysis performed as airflow analysis

1.5.4 Materials related to wind turbine (RNA) design evaluation

-1. The following documents shall be submitted to ClassNK as examination materials related to the wind turbine (RNA) design evaluation. The documents may be in a format that combines the following items.

(1) Report related to design basis (Contents described in 3.2.2)
(2) The values of the design load set at the time of the type certification (certification design load), and the site-specific load obtained from the integrated load analysis (site load), and a report on their comparison
(3) Report on strength calculations for the relevant RNA components in a case when the site load exceeds the certification design load
(4) Report on the change in the vibration mode/natural vibration frequency from the type certification conditions
(5) Reports on any components or systems that comprise the RNA that are not fully covered in the type certification, or that have been newly modified or enhanced for the site
(6) If a power back-up is provided, a report that confirms that the requirements specified in 5.4 are satisfied
(7) Materials summarizing the measures for safely stopping the wind turbine as specified in 5.5.1, and the results of the strength evaluation associated with those measures
(8) Materials summarizing the measures taken to protect against lightning strikes as specified in 5.5.2

1.5.5 Materials related to the support structure (Tower) design evaluation

-1. The following documents shall be submitted to ClassNK as examination materials related to the support structure (tower) design evaluation. The documents may be in a format that combines the following items.

(1) Report related to design basis (which may be common with the wind turbine design evaluation, including the contents described in 3.2.3-1)
(2) If a tower described in the type certificate is to be used, the values of the design load set at the time of the type certification (certification design load), and the site-specific load obtained from the integrated load analysis (site load), and a report on their comparison
(3) If the site load exceeds the certified design load in (2) above, or if a tower not mentioned in the type certificate is to be used, a report on the strength calculation of the structural design of the tower with the site load applied
(4) Report showing that the tower to be used satisfies the requirements of the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]
(5) Report including the results of consideration of the items specified in 6.2
(6) Report on the change in the vibration mode/natural vibration frequency from the type certification conditions

-2. If no application for examination for the support structure (Foundation) design evaluation is made, the following documents shall be submitted to ClassNK from among the examination materials specified in 1.5.6-1.

(1) Of the support structure strength calculation documents attached to the construction plan notification based on the Electricity Business Act, a report that corresponds to the following details
   - Geotechnical investigation
   - Seismic response analysis
   - Work execution plan
   - Special materials
   - Foundation drawings around tower anchorage zone

1.5.6 Materials related to the support structure (Foundation) design evaluation

-1. The following documents shall be submitted to ClassNK as examination materials related to the Support structure (Foundation) design evaluation.

(1) Support structure strength calculation documents attached to the construction plan notification based on the Electricity Business Act

(2) Overview materials on the support structure design (in case the Support Structure Certification Subcommittee Foundation and Ground Section Meeting specified in 1.4.9-4. is to be hold)

1.6 Correspondence to the Technical Standards for Wind Power Generation Facilities [Reference]

1.6.1 General

-1. The correspondence between the Technical Standards for Wind Power Generation Facilities and the requirements of these guidelines is as shown in Table 1-5.

Table 1-5 Correspondence between the Technical Standards for Wind Power Generation Facilities and the requirements of these guidelines

Technical Standards for Wind Power Generation Facilities (Excerpts from the original text, and temporary translation)	Related items in these guidelines
(Scope) Article 1. This Ministerial Ordinance shall apply to electric facilities installed to generate electricity by means of wind power. 2. The term "electric facilities" as used in the preceding paragraph shall refer to the Electric Facilities for General Use and Electric Facilities for Business Use.	Chapter 1. General
(Definitions) Article 2. The terms used in this Ministerial Ordinance shall have the same meanings as the terms used in the Rules for the Electricity Business Act (Ordinance of the Ministry of International Trade and Industry No. 77, 1995).	-
(Hazard prevention measures for persons other than operators) Article 3. When installing a wind power plant, the operator shall indicate that the wind turbine is dangerous at a place that is easy to see for persons other than the operator, and shall take appropriate measures to prevent those persons from easily approaching it. 2. If a wind power generation facility is the Electric Facility for General Use, the provisions of the preceding paragraph shall be applied by replacing the phrase "wind power plant" in the paragraph with "wind power generation facilities" and the phrase "those persons from easily approaching it" with "those persons from easily approaching the wind turbine".	-
(Wind turbine) Article 4. Wind turbines shall be installed in accordance with the following items. (i) To be structurally safe relative to the maximum speed when the load is cut off. (ii) To be structurally safe against wind pressure. (iii) To be equipped so that there are no vibrations that may damage the wind turbine during operation. (iv) To be equipped so that the wind turbine will not start up against the operator's intention, even at the maximum wind speed normally assumed. (v) To be equipped so as not to come into contact with other structures, plants, etc., during operation.	Chapter 2. Site conditions assessment 3. Design basis evaluation 4. Integrated load analysis evaluation 5. Wind turbine (RNA) design evaluation
(Ensuring the safety of wind turbines) Article 5. Measures shall be taken to ensure that wind turbines stop safely and automatically in the following cases. (i) When the rotational speed has increased significantly (ii) When the functioning of the control equipment for the wind turbine has significantly deteriorated 2. If a wind power generation facility is the Electric Facility for General Use, the provisions of the preceding paragraph shall be applied by replacing the phrase "Measures shall be taken to ensure that wind turbines stop safely and automatically" in the paragraph with "Measures shall be taken to ensure safe conditions". 3. For wind power generation facilities on which the highest part is more than 20	Chapter 2. Site conditions assessment 5. Wind turbine (RNA) design evaluation

Technical Standards for Wind Power Generation Facilities (Excerpts from the original text, and temporary translation)	Related items in these guidelines
meters above the ground surface, measures shall be taken to protect the wind turbine from lightning strikes. However, this shall not apply in a case where the surrounding conditions mean that there is no risk of lightning strikes damaging the wind turbine.	
(Prevention of dangers of oil pressure systems and compressed air devices) Article 6. The oil pressure systems and compressed air devices used as wind power generation equipment shall be installed in accordance with the following items. (i) The materials and structures of the pressure oil tank and air tank shall be sufficient to withstand the maximum allowable working pressure and be safe. (ii) The pressure oil tank and air tank shall have corrosion resistance. (iii) There shall be a function to reduce the pressure before it reaches the maximum allowable working pressure in the case that the pressure rises. (iv) There shall be a function to automatically recover the pressure in the case that the oil pressure of a pressure oil tank or the air pressure of an air tank decreases. (v) There shall be a function to detect abnormal pressure at an early stage.	-
(Structure to support the wind turbine) Article 7. The structure supporting the wind turbine shall be structurally safe against its own weight, loading capacity, snow and wind pressure, and against earthquakes and other vibrations and impacts. 2. If a wind power generation facility is the Electric Facilities for General Use, appropriate measures shall be taken to prevent a person other than the operator from easily climbing the structure supporting the wind turbine.	Chapter 2. Site conditions assessment 3. Design basis evaluation 4. Integrated load analysis evaluation 6. Support structure design evaluation
(Prevention of pollution, etc.) Article 8. The provisions of Article 19, paragraphs (11) and (13) of the Ministerial Ordinance Prescribing Technical Standards for Electric Facilities (Ordinance of the Ministry of International Trade and Industry No. 52, 1997) apply mutatis mutandis to wind power generation facilities installed in wind power plants. 2. If a wind power generation facility is the Electric Facility for General Use, the provisions of the preceding paragraph shall be applied by replacing the phrase "Article 19, paragraphs (11) and (13)" in the paragraph with "Article 19, paragraph (13)" and the phrase "wind power generation facilities installed in wind power plants" with "wind power generation facilities".	-

Chapter 2 Site conditions assessment

2.1 General

2.1.1 General

-1. Site-specific external conditions and parameters associated with the design must be considered to ensure an appropriate level of safety and reliability.

-2. The external conditions must be specified in such a way that they are the most severe for the structure, with consideration of an appropriate probability level.

2.2 Wind conditions during power production

2.2.1 Wind condition measurement

-1. The evaluation of the wind conditions during power production must be carried out using data acquired by using wind condition measurement masts installed at one or more points which are representative of the planned wind farm. The measurement period shall be a sufficient period to obtain reliable data and shall be at least one year to include seasonal effects.

-2. The measurement points shall be selected to represent the site-specific conditions (Topography, elevation, surface roughness, annual average wind speed, turbulence intensity, etc.) of the planned wind farm and the reasons shall be clearly stated. It is desirable to use airflow analysis in the selection of these representative points.

-3. As shown in Table 2.1, the observed height shall be not less than 2/3 of the planned hub height, regardless of the topography class. The distance between the measurement point and the wind turbine construction point must be within the representative radius corresponding to the topographic complexity as shown in Table 2.1.

-4. Anemometers for the wind speed and wind direction shall each be installed at multiple altitudes in a manner that minimizes the effects from the measurement mast and boom. Annex A may be followed for the installation method for wind condition measurement masts and measurement equipment.

-5. When it is difficult to take measurements at a position over 2/3 of the planned hub height when only using a wind condition measurement mast, the measurements may be taken in combination with remote sensing equipment such as a vertical lidar. Even in this case, the wind condition measurement mast must be made as tall as possible. In addition, the wind condition measurement mast and remote sensing equipment must carry out simultaneous measurement, and these measurement data must satisfy the requirement concerning the correlation shown in 2.2.2.

Table 2-1 Observed height and representative radius

Topography class*	Measured height	Representative radius of the measurement mast
Simple / Flat terrain	At least 2/3 of hub height	10 km or less
Complex terrain	At least 2/3 of hub height	2 km or less

*: The topography class is determined based on the evaluation of the topographic complexity shown in 2.2.3.

2.2.2 Measurement data evaluation

-1. The evaluation of the external conditions at the site must be carried out using wind condition measurement data that has been acquired in a form which satisfies the requirements in 2.2.1.

-2. The wind condition measurement data to be used as the input data in the airflow analysis shown in 2.2.4 must be from one year or longer and the effective data rate must be 95% or higher. (In principle, the measurement data from the highest position on the measurement mast is to be used.)

-3. If there is a period in which the wind condition measurement data is missing, or a period that contains abnormal values, such as due to the failure of measurement equipment, the wind condition measurement data must be complemented by an appropriate method. The effective data rate after the complementation processing should be 95% or higher.

-4. In principle, the effective data rate of the anemometers for the wind speed and wind direction that are used to complement the data in -3. above shall be 90% or more. Also, if the MCP method is used to complement the data by using other measurement data measured within the site, or data from a nearby meteorological observatory, then in principle, the correlation coefficient shall be 0.8 or higher. In addition, for confirmation of the validity of the complementation method, the results of the comparison of the values applied with the measured values from a period without missing data shall be shown.

-5. Regarding wind condition measurement data, comparison with normal year values must be carried out using appropriate reference data such as reanalysis data by a meteorological model and long-term measurement data from a meteorological observatory close to the site, and appropriate corrections must be made.

-6. The cause must be investigated if the wind condition measurement data contains a peculiar tendency, such as a case in which the wind direction of adjoining altitudes greatly differs, or a case in which the wind shear exponent of a part of the wind direction greatly differs from the others.

-7. It must be confirmed that measurement data from remote sensing equipment is appropriate as measurement data by confirming that there is a correlation with the measurement data from a wind condition measurement mast on which simultaneous measurement was carried out in accordance with Table 2-2, according to the following conditions. In any case, the principle is to use the measurement data from the highest position on the wind condition measurement mast.

(1) When the measurement data from a measurement mast and from remote sensing equipment is combined and treated as hub-height measurement data for the input data for airflow analysis

(2) When measurement data from a measurement mast is used as the input data for airflow analysis, and the measurement data from remote sensing equipment is only used to verify the validity of that airflow analysis.

-8. The effective data rate of measurement data from remote sensing equipment shall be in accordance with -2. above. However, if the mast measurement data is used as input data for airflow analysis and the measurement data from the remote sensing equipment is only used to verify the validity of the airflow analysis, then it is not necessary for the effective data rate to be in accordance with the provisions of -2. above, provided that it is quantitatively shown that the effects of seasonality are sufficiently obtained.

Table 2-2 Correlation of measurement data from a measurement mast and remote sensing equipment

Condition	Requirements for wind speed	Requirements for wind direction
(1)	• Coefficient of determination R^2: > 0.98 • Slope of the regression line: 0.98 to 1.02	• Coefficient of determination R^2: > 0.97 • Slope of the regression line: 0.97 to 1.03 • Intercept of the regression line: < 5°
(2)	• Coefficient of determination R^2: > 0.97 • Slope of the regression line: 0.97 to 1.03 *When these requirements are not satisfied, the reason must be quantitatively shown using the results of airflow analysis, etc.	• Coefficient of determination R^2: > 0.95 • Slope of the regression line: 0.95 to 1.05 • Intercept of the regression line: < 10° *When these requirements are not satisfied, the reason must be quantitatively shown using the results of airflow analysis, etc.

2.2.3 Evaluation of topographic complexity

-1. In order to select a model for airflow analysis and to evaluate the number of wind direction sectors, the turbulence structure correction parameters (hereinafter, C_{CT}) must be calculated for the measurement mast position and the wind turbine position in order to judge the topographic complexity at each position. The specific method of judgment shall follow one of the following.

(1) JIS C 1400-1:2017[J-01], paragraph 11.2 (IEC 61400-1 Ed.3.1, 11.2)

(2) IEC 61400-1:2019 [J-02], 11.2

-2. If there is even one measurement mast or wind turbine in the planned site with $C_{CT} \geq 1.05$, then the site shall be treated as corresponding to complex terrain.

2.2.4 Airflow analysis

-1. In order to predict the wind condition at the wind turbine position, the airflow analysis must be performed appropriately. The model applied to the airflow analysis and the number of wind direction sectors to be considered shall be as shown in Table 2.3.

Table 2-3 Airflow analysis model and requirements for the number of wind direction sectors

Topographic complexity	Airflow analysis model	Number of wind direction sectors
Simple / Flat terrain	Linear model/Nonlinear model	12 or more
Complex terrain	Non-linear model	16 or more

-2. For the airflow analysis, the appropriate terrain model must be selected according to the terrain of the planned site and the situation in the surrounding area, and also a sufficient analysis area must be secured. The details of the airflow analysis shall be in accordance with Annex B.1.

-3. The validity of the airflow analysis must be fully confirmed. The validity of the airflow analysis must be verified by using the airflow analysis to calculate the wind conditions at the position of the wind condition measurement mast and then comparing the results with the measurement data regarding the average wind speed, turbulence intensity, and wind shear for each direction. The details of this confirmation of the validity of the airflow analysis shall follow Annex B.2.

2.2.5 Calculation of the wind speed appearance frequency distribution

-1. The site wind condition measurement data and airflow analysis results shall be used to calculate the appearance frequency by direction and Weibull parameter by direction at the hub height at the wind turbine position.

-2. In addition to the appearance frequency by direction, the energy density by direction must also be calculated.

-3. Annex C.2.1 may be followed for the calculation of the Weibull parameter.

2.2.6 Calculation of turbulence intensity

-1. For the turbulence intensity by direction at the hub height at the wind turbine position, the site wind condition measurement data and airflow analysis results shall be used to calculate each of the turbulence intensities corresponding to the normal turbulence model (NTM) and the extreme turbulence model (ETM) prescribed in JIS C 1400-1:2017 [J-01]. Also, with regards to the wind turbine operation, the effect must be appropriately considered if sector management will be set.

-2. In order to calculate I_{rep}, which is the turbulence intensity corresponding to the normal turbulence model (NTM), it is necessary to calculate the ambient turbulence standard deviation $\hat{\sigma}$ in V_{hub} between V_{in} and V_{out}, and the standard deviation $\hat{\sigma}_{\sigma}$ of $\hat{\sigma}$.

-3. For the turbulence intensity corresponding to the extreme turbulence model (ETM), it is possible to use the turbulence intensity using the maximum value of the ambient turbulence standard deviation $\hat{\sigma}$ in V_{hub} between V_{in} and V_{out}.

-4. Note that for the standard deviation of turbulence, it is necessary to calculate not only for the principal direction component $\hat{\sigma}_1$, but also for the lateral direction component $\hat{\sigma}_2$ and vertical direction component $\hat{\sigma}_3$ of the principal direction (See 4.2.2-3).

-5. Annex C.2.2 may be followed for the specific method for calculating the turbulence intensity.

2.2.7 Evaluation of wind turbine wake effect from adjacent wind turbines

-1. The intensity of the surrounding turbulence at the hub height at the wind turbine position that was found in 2.2.6 shall be used to appropriately evaluate the effect of the wake flow from adjacent wind turbines during power production. Also, with regards to the wind turbine operation, the effect must be appropriately considered if sector management will be set.

-2. Turbulence characteristics considering single or multiple wake flows from the wind turbines located upwind shall be considered for all the ambient wind speeds and directions related to power generation, including consideration of the effect of the distance between wind turbines. Also, when evaluating the wake flow effect, it is necessary to consider all of the wind turbines located within a distance of 10 D from the wind turbine being evaluated. In this case, D is the rotor diameter of the adjacent wind turbines.

-3. For the consideration of the effects of ambient turbulence and discrete turbulent wakes, it is possible to use the effective turbulence intensity (hereinafter, I_{eff}). This I_{eff} shall be calculated using the model given in either of the following.

(1) JIS C 1400-1:2017[J-01], Annex D (IEC 61400-1 Ed.3.1, Annex D)

(2) IEC 61400-1:2019 [J-02], Annex E

-4. In the case of a large-scale wind farm, for I_{eff}, the case when the Frandsen model is applied based on JIS C 1400-1:2017[J-01] Annex D shall be compared with the case when the provisions concerning the large-scale wind farm effect are used, and the validity of these shall be verified to judge which method to use for the calculation.

-5. For the extreme turbulence including the wake effects, it is possible to use the maximum turbulence at the center of the wake in the most severe direction.

2.2.8 Calculation of the wind shear exponent

-1. The site wind condition measurement data and airflow analysis results shall be used to calculate the wind shear exponent by direction vertically of the wind receiving surface of the rotor at the wind turbine position.

-2. When the weighted average based on energy density is calculated for the wind shear exponent by direction that was found in -1. above, if a value less than 0.2 is obtained, then the value shall be assumed to be 0.2.

-3. Annex C.2.3 may be followed for the specific method for calculating the wind shear exponent.

2.2.9 Calculation of flow inclination angle

-1. The site wind condition measurement data and airflow analysis results shall be used to calculate the inflow angle by direction at the hub height at the wind turbine position.

-2. When the representative value as all wind direction of inflow angle by direction that was found in -1. above, the weighted average based on energy density may be calculated.

-3. Annex C.2.4 may be followed for the specific method for calculating the flow inclination angle.

2.2.10 Calculation of atmospheric density

-1. The atmospheric density at the site must be calculated using field measurement data.

-2. Annex C.2.5 may be followed for the specific method for calculating the atmospheric density.

2.3 Wind conditions during parked by storm

2.3.1 Calculation of extreme wind speed and turbulence intensity

-1. It is necessary to calculate the 10 minutes average wind speed with a return period of 50 years at wind turbine position and hub height U_h, and the turbulence intensity I_{h1} and 3-second average wind speed U_{e50} for that U_h. The methods used to calculate these must be in accordance with Annexes C.3.1 and C.3.2, which comply with the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05].

-2. The validity of the airflow analysis used for the calculation in -1. above must be sufficiently confirmed. The validity of the airflow analysis must be verified by using the airflow analysis to calculate the wind conditions at the position of the wind condition measurement mast and then comparing the results with the measurement data regarding the average wind speed, turbulence intensity, and wind shear for each direction. The confirmation of the validity of the airflow analysis shall be conducted in accordance with Annex B.2.

-3. For U_{e50}, the value may be determined by calculating I_{h1} in accordance with Annex C.3.3 and based on appropriate measurement data meeting the criteria given in 2.2.2.

-4. For the 10 minutes average wind speed with a return period of 1 year U_1, in accordance with JIS C 1400-1:2017[J-01], the value used shall be 0.8 times the 10 minutes average wind speed with a return period of 50 years U_h. In addition, instead of this, a calculated value based on long-term measurement data, etc., may also be used. However, in that case, the validity of the measurement data itself and the validity of the analysis method, etc., must be sufficiently shown.

-5. For the wind shear exponent for extreme wind speeds with a return periods of 50 years and 1 year, the highest value of the following items shall be adopted.

(1) The wind shear exponent for the surface roughness category specified in Table C.1 of Annex C

(2) The wind shear exponent corresponding to the 10 minutes average wind speed with a return period of 50 years as specified in JIS C 1400-1:2017[J-01]

(3) The wind shear exponent corresponding to the 10 minutes average wind speed with a return period of 50 years as specified in Annex C.3.2.3

2.3.2 Calculation of atmospheric density

-1. The atmospheric density corresponding to the extreme wind speed at the site shall be 1.22 kg/m^3 or higher.

2.4 Geotechnical and earthquake conditions

2.4.1 General

-1. Geotechnical and earthquake conditions shall be set in compliance with the requirements of the following Ministerial Ordinance and Guidelines.

(1) Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities[J-03]

(2) Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]

-2. The following points shall be taken into consideration when calculating the conditions in accordance with -1. above.

(1) An investigation must be conducted regarding the situation of damage caused by past earthquakes and any accompanying liquefaction or tsunami, and the results must be used as a reference.

(2) When setting the engineering base surface, it must be confirmed that the shear wave velocity is 400 m/s or higher, the layer thickness is 5 m or higher, and the inclination is 5 degrees or less (conditions of application of one-dimensional wave theory).

(3) The impact of tsunamis must be considered. Also, when investigating that impact by using hazard maps, the grounds for the hazard maps must be clarified.

(4) When borehole lateral load testing is carried out for the estimation of the modulus of deformation, the results must be appropriately summarized and shown.

(5) When Ota and Goto's equation is used to estimate the shear wave velocity, the validity of the estimation must be verified based on the results of ground investigations, and the effect of the dispersion of the estimated values must be evaluated.

-3. When the distinction between onshore and offshore is not clear for the planned construction site, the handling shall be as judged appropriate by ClassNK.

2.5 Lightning environment conditions

2.5.1 General

-1. Regarding the lightning environment conditions at the planned installation site for a wind turbine or wind farm, the regional characteristics must be evaluated by using data such as the frequency of lightning and the distribution of lightning days.

-2. The frequency of lightning strikes in each area is classified into the three categories shown in Figure 2-1, which are the areas surrounded by solid lines, the areas surrounded by dashed lines and other areas.

2.6 Other environmental conditions

2.6.1 General

-1. Depending on the characteristics of the site, the possibility of effects from the following environmental conditions shall be considered.

(1) Normal temperatures and extreme temperatures

(2) Design vertical snow depth and icing

(3) Humidity

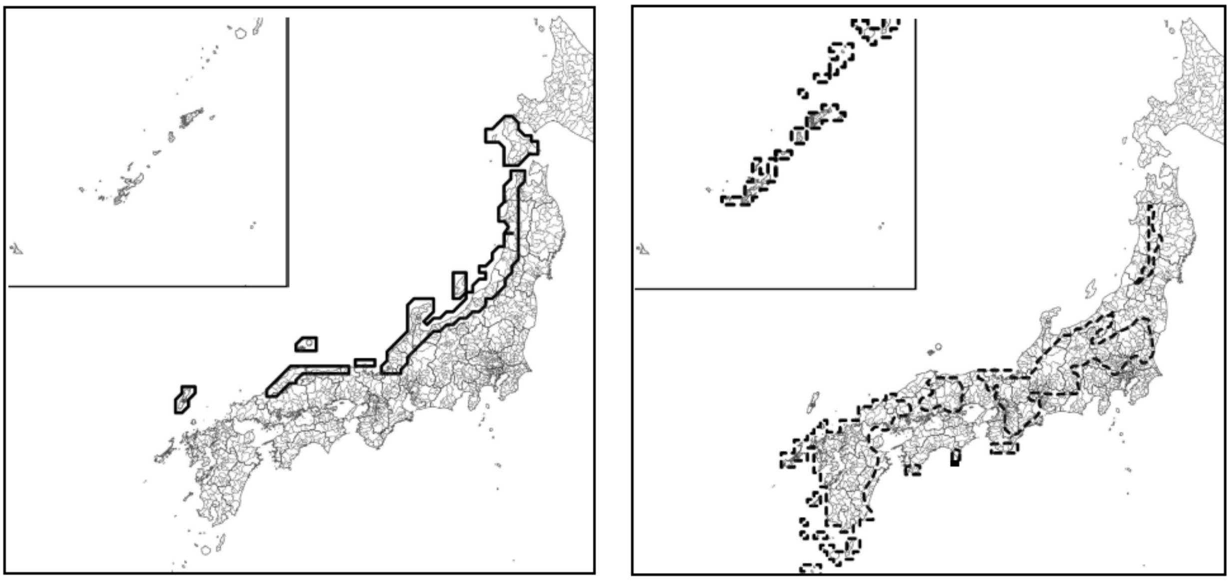

Figure 2-1 Frequency of lightning strikes by region

Chapter 3 Design basis evaluation

3.1 General

3.1.1 General

-1. The purpose of the design basis evaluation is to examine whether the design basis has been properly documented and is sufficient for safe design and project execution.

3.2 Design basis requirements

3.2.1 General

-1. The design basis includes the following items.

(1) Site conditions

(2) Design methodologies and principles

(3) Codes and standards which form the basis for the project

(4) Wind turbine type; main specifications or type certificate with identifications of deviations

(5) Support structure specifications

-2. The design basis shall include all relevant overall design aspects and the parameters to be applied in the calculation of site conditions, loads, design load cases, partial safety factors applied to loads and materials, geometric tolerances, corrosion allowance growth, etc.

3.2.2 Wind turbine (RNA) design basis

-1. The document which shows the design basis for the wind turbine shall describe how the following matters were decided.

(1) Codes and standards

(2) Site conditions

- Wind conditions during power production
  - Turbulence intensity correction parameter: C_{CT} (at measurement mast position / at wind turbine position)
  - Average wind speed (hub height at wind turbine positions)
  - Turbulence intensity [Normal turbulence model (NTM) and extreme turbulence model (ETM)] (hub height at wind turbine positions)
  - Wind shear exponent (hub height at wind turbine positions)
  - Flow inclination angle (hub height at wind turbine positions)
  - Air density (hub height at wind turbine positions)
  - Design temperature range (hub height at wind turbine positions)
  - Other conditions set in the type certification
- Wind conditions during parked by storm
  - 10 minutes average wind speed with a return period of 50 years (hub height at wind turbine positions)
  - 3 seconds average wind speed with a return period of 50 years (hub height at wind turbine positions)
  - 10 minutes average wind speed with a return period of 1 year (hub height at wind turbine positions)
  - 3 seconds average wind speed with a return period of 1 year (hub height at wind turbine positions)
  - Turbulence intensities for wind speeds with a return period of 50 years and 1 year (hub height at wind turbine positions)
  - Wind shear exponents for wind speeds with a return period of 50 years and 1 year (hub height at wind turbine positions)
  - Air densities for wind speeds with a return period 50 years and 1 year (hub height at wind turbine positions)
  - Other conditions set in the type certification

(3) Wind turbine operating conditions
   - Cut-in wind speed, cut-out wind speed, rated wind speed, rated power generation, etc.
   - Whether or not sector management has been set, and if it is set, details thereof
   - If there will be operation at high wind speeds with the power generation lowered, the operating conditions in that case (Clear indication of power curve and operation control)
   - Operating conditions and specific control logic when the turbine continues to operate with power back up during a loss of electrical power while parked (if applicable)

(4) If there is any change from the wind turbine specifications or the specifications at the time of the type certification, a comparison of the specifications before and after that change
(5) Design parameters related to the load calculations, and the validity of applying the load analysis method used
(6) Load case table
(7) Load factors and load reduction factors
(8) Overview of the load analysis model
(9) Duration of the simulation and its time
(10) Extreme and fatigue design loads and response analysis
(11) Other items deemed necessary by ClassNK

3.2.3 Support structure design basis

-1. The document which shows the design basis for the support structure (tower) shall describe how the following matters were decided.

(1) Codes and standards
(2) Site conditions
(3) Support structure specifications
(4) Design policy (Required performance and verification items, materials used and material constants, allowable tolerance of shape and corrosion reserve thickness, etc.)
(5) Load analysis method, and the validity of the application of that method
(6) Partial safety factors and load reduction factors for each load, and the validity of the application of those factors
(7) Evaluation method for ultimate and fatigue strength, and the validity of the application of that method

-2. Regarding the design basis for the support structure (foundation), in principle, it is acceptable to follow the regulations in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05].

Chapter 4 Integrated load analysis evaluation

4.1 General

4.1.1 General

-1. The purpose of the integrated load analysis is to evaluate whether the site-specific loads and load effects on the integrated wind turbine structure, which includes the rotor-nacelle assembly (RNA) plus the support structure and supporting soils, are derived in conformity with the design basis.

4.2 Requirements for load analysis for RNA and tower evaluation

4.2.1 Comparison of the site conditions and the design values set in the type certification

-1. The load analysis based on site conditions prescribed in Chapter 2 is not required when the below two conditions are satisfied. One is that the conditions and requirements of the design basis relating to the site conditions and load effects necessary for the calculation of loads are lower than those set in the type certification. Another is it is confirmed by ClassNK that the characteristics including the control of the wind turbine are the same as those set in the type certification.

-2. In the confirmation of -1. above, it is necessary to follow JIS C 1400-1:2017[J-01] 11.9 and compare the site-specific design conditions with the design values set in the type certification, based on the site conditions specified in Chapter 2. Of the site conditions specified in Chapter 2, for the turbulence intensity, the value obtained by multiplying the principal direction component of I_{eff} specified in 2.2.7 (or I_{rep} specified in 2.2.6 if there is no adjacent wind turbine), by the C_{CT} specified in 2.2.3 must be compared with the principal direction component of the turbulence intensity set in the type certification for each wind speed bin.

-3. In the confirmation of -2. above, if it is found that some items deviate from the design values set in the type certification, or if the characteristics including the control of the wind turbine are different from those set in the type certification, the load analysis prescribed in 4.2.2 shall be carried out based on the site conditions prescribed in Chapter 2.

4.2.2 Load analysis

-1. For the load analysis based on the site conditions, in principle, all of the design load cases applied at the time of type certification shall be targeted, and the analysis model and analysis method applied at the time of type certification shall be used. If a design load case applied at the time of type certification is omitted, the reason why it may be omitted shall be indicated.

-2. In the case of a wind turbine with a power back-up as a measure for use in the event of a loss of the electrical power network, evaluation must be carried out according to 5.3, and a design load case to be applied in the ultimate load analysis must be decided.

-3. In the load analysis, the components of the turbulence intensity in three directions that were determined in 2.2.6 must be properly considered. In a case where there is no site data for the turbulence components, and also the terrain is complex, for the turbulence standard deviations of the lateral direction and vertical direction against the principal direction component, it can be assumed that the ratios to the principal direction component are 1.0 and 0.7 respectively. These may also be calculated by using C_{CT} and applying equations (2.1) and (2.2). In this case, it is not necessary to multiply the principal direction component prescribed in 4.2.1-2 by C_{CT}.

$$\hat{\sigma}_2 = 1.15 \times 0.8 \times C_{CT} \times \hat{\sigma}_1 \tag{2.1}$$
$$\hat{\sigma}_3 = 1.15 \times 0.5 \times C_{CT} \times \hat{\sigma}_1 \tag{2.2}$$

-4. The definition of the site load to be calculated shall be clearly indicated, and the coordinate definition applied in that site load calculation shall be clearly indicated in a diagram. In principle, the definition specified in IEC 61400-13:2015[R-16] shall be used for the coordinate definition.

-5. For the extreme wind conditions at the site that are to be applied to the load analysis, the combinations that produce the maximum load shall be selected appropriately, by taking into account the highest of each of the 10 minutes average wind speed, the 3 second average wind speed and the wind shear exponent.

-6. If the extreme wind speed at the site greatly exceeds the design wind speed in the type certification, it must be sufficiently verified whether it is possible to apply the load analysis method applied for the extreme wind speed condition that was applied during the type certification.

-7. In the case of a wind turbine which carries out passive yaw control (free yaw, etc.) in the standby state, the setting of the design load case is based on what ClassNK separately approves as appropriate.

4.3 Requirements for load analysis for support structure evaluation

4.3.1 General

-1. Load analysis concerning the evaluation of support structures shall be carried out in accordance with the requirements of the following Ministerial Ordinance and Guidelines.

(1) Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities[J-03]

(2) Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]

4.3.2 Support structure load analysis

-1. In addition to the load calculated in 4.3.1-1., the loading data for the foundation and the tower design load at the site shall be set by following the provisions of paragraphs 2.2 and 4.1.2 of the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and appropriately considering the load applied to the tower at the time of the type certification, and the site load on the tower that was calculated based on the site conditions specified in 4.2.2.

-2. Annex F.2 shall be followed to calculate the structural damping ratio to be set for the tower in the analytical model applied to the seismic response analysis carried out in accordance with the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05].

-3. In the seismic response analysis, appropriate consideration shall be given to the effects of the wind turbine blade mass and rigidity distribution.

-4. When equivalent linear analysis is carried out in the seismic response analysis, if the shearing strain exceeds 1% in the results, then it is not possible to apply the response calculation flow for liquefied ground that is described in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05] (p. 170, Illustration 5.11). In this case, it should be noted that it is necessary to use an alternative method such as effective stress analysis.

-5. In the case of pile foundations, if ground springs are set using the thin layer method, etc., and not by following the provisions of the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], the validity of the setting should be appropriately indicated.

Chapter 5 Wind turbine (RNA) design evaluation

5.1 General

5.1.1 General

-1. The structural integrity of the wind turbine for the site conditions shall be indicated by comparing the site-specific loads obtained by the integrated load analysis with the design loads used in the type certification.

-2. If there are new components, improved or reinforced components, or new or improved systems not listed in the wind turbine type certificate, the relevant components and systems shall also comply with the requirements for type certification.

-3. In the case of a wind turbine which has not acquired type certification, the handling shall be as judged appropriate by ClassNK.

5.2 Wind turbine (RNA) design evaluation

5.2.1 Comparison of site loads with design loads at type certification

-1. If the load from the integrated load analysis carried out based on the site conditions (hereinafter called the site load) does not exceed the design load applied at the time of type certification (hereinafter called the certified design load), the site conditions may be considered to satisfy the design values at the time of type certification, and the structural integrity of the wind turbine against the site conditions may be ensured.

-2. With regards to the points to be evaluated in a comparison of the site-specific load with the allowable design load in order to show the contents of -1. above, at least the following items must be taken into consideration and also any evaluation points other than those below must be set as appropriate for the RNA specification and structure. In addition, it must be clearly shown that the items selected are sufficient to show the structural integrity of the RNA.

(1) Six or more cross-sectional positions including the blade root portion and the portion where the maximum load is applied other than the blade root portion
(2) Blade bearing
(3) Pitch system
(4) Hub (when fixed) and hub (during operation and during idling)
(5) Main shaft and main shaft bearing
(6) Yaw system
(7) Tower top/Joining part between tower top and nacelle
(8) Nacelle frame
(9) Other major components requiring evaluation

-3. The design documents concerning the certified design load described in the certification evaluation report of the Design Evaluation Conformity Statement shall be submitted to ClassNK as data for the confirmation of the certified design load.

5.2.2 Strength evaluation of the components of the RNA based on the site load

-1. If the site load exceeds the certified design load, the integrity of the affected components against the site load must be verified.

-2. In the verification in -1. above, the response and applied stresses, etc., from the site load must be obtained based on a strength evaluation with the same design methodologies and thinking on safety factors, etc., as those applied at the time of the type certification (hereinafter called the original design method), and the allowance for the proof stress peculiar to the components must be shown. When any judgment is made in this strength evaluation, the grounds for the validity of that judgment shall be indicated by citing international standards and guidelines.

-3. When citing the original design methodology in the strength evaluation based on the site load, the documents which can be used to confirm the details of the original design method indicated in the type certificate, the related conformity statement and its certification evaluation report shall be submitted to ClassNK as reference materials.

-4. In the report which summarizes the strength evaluation based on the site load, a table shall be included which lists each individual component verified and shows the excess ratio of the site load to the certified design load and the tolerance obtained from the results of the strength evaluation shown in -2. above for each component as a summary. The basis for the values in that table shall be clearly indicated in an appropriate manner, such as by attaching a detailed statement to the report or by citing a separate volume.

5.3 Nacelle cover strength evaluation

5.3.1 General

-1. The nacelle cover shall be of sufficient strength against the wind load established under the site conditions.

5.3.2 Wind load on the nacelle cover

-1. The wind load factor for the nacelle cover shall be calculated by using equation (5.1).

$$P_e = \frac{1}{2}\rho {U_h}^2 \hat{C}_p \tag{5.1}$$

Where:

ρ : Air density, which shall be 1.22 $[kg/m^3]$
U_h : 10 minutes average wind speed with a return period of 50 years $[m/s]$ as specified in 2.3.1
$\hat{C}_p$: Peak wind force coefficient, determined by equation (5.2).

$$\hat{C}_p = \hat{C}_{pe} - C_{pi} \tag{5.2}$$

Where:

$\hat{C}_{pe}$: Peak external pressure coefficient
C_{pi} : Internal pressure coefficient, according to Table 5-1

Table 5-1 Internal pressure coefficient

	Negative pressure side	Positive pressure side
There is no opening on the upwind side surface	0	-0.5
There is an opening on the upwind side surface	0.5	0

-2. The peak external pressure coefficient shall be calculated by using equation (5.3).

$$\hat{C}_{pe} = \hat{C}_{em}(1 + 7I_{h1}) \tag{5.3}$$

Where:

$\hat{C}_{em}$: Equivalent wind pressure coefficient, a reference example of which is given in Annex D
I_{h1} : Turbulence intensity for 10 minutes average wind speed with a return period of 50 years shown in 2.3.1

-3. The peak external pressure coefficient may be set based on the results of wind tunnel testing in place of the provisions given in -2. above. Annex E can be used as a reference for conducting wind tunnel tests.

5.3.3 Load cases

-1. The wind load acting on the nacelle cover shall be calculated with all of the load cases given in Table 5-2 taken into consideration. Note that the load cases shown in Table 5-2 are those among the design load cases specified in JIS C 1400-1:2017[J-01] that correspond to the wind speed, wind direction, and turbulence intensity to be considered in DLC6.1 and DLC6.2, with the wind directions being those that should be considered in the $\hat{C}_{em}$ calculation.
-2. The wind load for each load case shall be calculated using equation (5.1) and multiplied by the partial safety factor shown in Table 5-2.

Table 5-2 Load cases to be applied to the nacelle cover load calculation

No.	$\hat{C}_{em}$	$\hat{C}_{em}$ Wind direction to be taken into consideration in the calculation	Wind speed	Turbulence intensity	Partial safety factor for wind loads
NC.1-1	Positive value	-15° to +15° *1	U_h	I_{h1}	1.35
NC.1-2	Negative value				
NC.2-1	Positive value	All wind directions *2	U_h	I_{h1}	1.10
NC.2-2	Negative value				

*1: Corresponds to the wind direction to be considered in DLC6.1 specified in JIS C 1400-1:2017[J-01]

*2: Corresponds to the wind direction to be considered in DLC6.2 specified in JIS C 1400-1:2017[J-01]

5.3.4 Strength evaluation

-1. In principle, the method used for the strength evaluation for the nacelle cover against the wind loads calculated based on the site conditions and in accordance with 5.3.3 shall be the same as the strength evaluation method applied at the time of type certification, and the setting of the tolerance values, etc., may also follow that method.

-2. Notwithstanding -1. above, if composite materials are used on the nacelle cover, the partial safety factors related to the material, manufacturing, and long-term deterioration, etc., shall be appropriately taken into consideration, and the product of these partial safety factors shall not be less than 2.0.

5.4 Evaluation in the event of the electrical power network loss

5.4.1 General

-1. The wind turbine must ensure the safety of the wind turbine regarding the following items, even if the electrical power network is lost.

(1) Measures to automatically shut down in the event of a loss of electrical power network

(2) Maintenance of a safe state until the electrical power network returns

-2. Regarding -1. (2) above, it shall be ensured as a design load case to be applied to the integrated load analysis by considering the DLC6.2 specified in JIS C 1400:2017[J-01].

-3. In order to satisfy the requirements of -1. above, when the control of the wind turbine will be continued by using power back-up in the event of the electrical power network loss, DLC6.2 may be omitted from the design load cases to be applied to the integrated load analysis by satisfying all the requirements shown in 5.4.2.

5.4.2 Power back-up

-1. When a power back-up will be used to continue the control of the wind turbine in the event of the electrical power network loss, the following items (1) to (4) must be satisfied.

(1) In addition to clearly stating the yaw misalignment at which the maximum wind pressure occurs in the design, the certainty of the yaw misalignment to be adopted as the design value must be verified by measurement data from a reliable period and number of times.

(2) Whichever is the largest of the yaw misalignment design value obtained from the results of (1) above and ± 8° must be adopted as the yaw error parameter in the DLC6.1 specified in JIS C 1400:2017[J-01] among the design load cases used in the integrated load analysis specified in Chapter 4.

(3) The power back-up capacity must be set appropriately based on the site-specific conditions.

(4) The reliability of the systems related to the power back-up must be ensured, and the parameters related to the supply of the power back-up must be set appropriately.

-2. When setting design values for yaw misalignment, the following items (1) to (8) must be evaluated and confirmed under site-specific extreme wind speed conditions. In addition, the validity of the evaluation and confirmation of these items must be shown by measured data.

(1) With regard to the anemometers for wind speed and wind direction which obtain the measurement values necessary for yaw control, the usability and measurement accuracy in the extreme wind speed conditions specific to the site shall be

ensured, and the anemometers including their mounting portions shall have sufficient strength under the site-specific extreme wind speed conditions.

(2) The yaw control logic to follow the wind direction and the control logic for the equipment related to yaw control must be able to ensure the design values for yaw misalignment.

(3) The yaw drive and yaw brake specifications must be appropriate for the control logic for the yaw control.

(4) Either the pitch control mechanism or lock mechanism necessary to maintain the blade feather state must be provided, and the mechanisms must have sufficient strength under the site-specific extreme wind speed conditions.

(5) The load calculation must be performed by using a simulation method that can appropriately reproduce the conditions in which the extreme wind speeds specific to the site occur.

(6) There must have been appropriate consideration of the driving force (when the wind torque acts in the opposite direction to the direction of yaw movement) and braking force (when the wind torque acts in the direction of yaw movement) necessary for yaw control under the site-specific extreme wind speed conditions, which are provided by the wind torque, yaw drive torque and yaw brake, etc., and the equipment related to yaw control must have sufficient strength in that state.

(7) Even when a fail-safe approach is applied, there must be the driving force necessary for yaw control, for example, when a part of the yaw drive or yaw brake related to yaw control fails for some reason.

(8) Other items deemed necessary by ClassNK for each individual wind turbine

-3. The capacity of the power back-up shall be determined by calculating the amount of power required for yaw control and the other minimum control necessary based on the estimated storm duration and wind direction deviation during that time. When calculating that electric power, the larger of the storm durations or wind direction deviations calculated in (1) and (2) below must be adopted, and sufficient capacity must be secured for the conditions.

(1) Obtain the maximum storm duration and maximum wind direction deviation from a typhoon simulation using the site-specific conditions and calculate the amount of electric power required for yaw control and related control under conditions where both of these occur simultaneously. The definition of a storm in this case must be set individually because it differs depending on the control and design policy.

(2) Use the reference wind speed V_0 of the site and define the maximum storm duration as the numerical value obtained by "$V_0 - 24$". Assume that the wind direction deviation occurs $180°$ within that time, and calculate the amount of electric power required for yaw control and related control under those conditions.

-4. If the electrical power network is lost and the system is operated with a power back-up, the system must not automatically return to normal operation. The operation manual shall specify that normal operation can only be resumed when it has been confirmed in inspections that there is no abnormality.

-5. When an upwind wind turbine performs downwind control during parked by storm, it must satisfy separate requirements recognized as appropriate by ClassNK in addition to the requirements in -1. to -3. above.

5.5 Evaluation to secure a safe state on the wind turbine

5.5.1 Safe and automatic shutdown of wind turbines

-1. Even in the following cases, there shall be a function to stop safely and automatically, and also the safe state after stopping shall be maintained.

(1) When the rotational speed has increased significantly

(2) When the functioning of the control equipment for the wind turbine has significantly deteriorated

-2. Appropriate measures shall be taken for the following items.

(1) There must also be sufficient strength against the maximum rotational speed that is expected when the load is cut off.

(2) There must be no occurrence of resonance which affects the structural strength during operation.

(3) A startup shall not be allowed when the cutout wind speed is exceeded.

5.5.2 Protection against lightning strikes

-1. The provisions of this section are based on the Annotations to the Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities and its Interpretation[R-02], and there is no change to those requirements.

-2. For wind power generation facilities on which the highest part is more than 20 meters above the ground surface, measures shall be taken to protect the wind turbine from lightning strikes. However, this shall not apply in a case where the surrounding conditions mean that there is no risk of lightning strikes damaging the wind turbine. [Ministerial Ordinance, Article 5, paragraph (3)]

-3. "Measures to protect the wind turbine from lightning strikes" refers to wind turbines that satisfy all of the following requirements specified for the categories of areas, taking into consideration the lightning strike conditions at the location where the wind power generation facilities will be installed. [Interpretation, Article 7, paragraph (6) item (i)]

(1) Regions enclosed by solid lines in Figure 2-1

(a) The design must assume a lightning strike on the wind turbine with an electric charge of 600 coulombs or more.

(b) An appropriate receptor which is highly effective at protecting the wind turbine from lightning strikes and does not easily fall off must be attached to the wind turbine.

(c) A down conductor, etc., through which the current generated by a lightning strike can flow safely into the ground without damaging the wind turbine must be provided.

(d) An emergency stop device, etc., that can be used to stop the wind turbine immediately in the event of lightning striking the wind turbine must be provided.

(2) Regions enclosed by dashed lines in Figure 2-1

(a) The design must assume a lightning strike on the wind turbine with an electric charge of 300 coulombs or more.

(b) The requirements set forth in (1) (b) and (1) (c) shall be satisfied.

(3) Areas other than those enclosed by solid or dashed lines in Figure 2-1

(a) The design must assume a lightning strike on the wind turbine with an electric charge of 150 coulombs or more.

(b) The requirements set forth in (1) (b) and (1) (c) shall be satisfied.

-4. Lightning protection equipment which satisfies all of the following requirements must be installed for protection from lightning on parts at a height of 20 m or more on the structure supporting the wind turbine (except for items that are subject to the provisions of Article 2, Paragraph 1 of the Ship Safety Act (Act No. 11 of 1933).) [Interpretation, Article 7, paragraph (6) item (ii)]

(1) The lightning protection through which the current generated by a lightning strike can flow safely into the ground without damaging the structures that support the wind turbine must conform to JIS C 1400-24:2014[R-08].

(2) The parts of the lightning protection facilities which are liable to be corroded by rainwater, etc., must either be made of corrosion-resistant materials or provided with effective measures for corrosion prevention.

-5. The provision in -2. above that, "this shall not apply in a case where the surrounding conditions mean that there is no risk of lightning strikes damaging the wind turbine" shall include cases where a lightning conductor tower, lightning rod or other lightning arrester equipment is installed to protect the wind turbine concerned. [Interpretation, Article 7, paragraph (7)]

Chapter 6 Support structure design evaluation

6.1 General

6.1.1 General

-1. The design of the support structure (tower and foundation) shall comply with the following ministerial ordinances and guidelines.

(1) Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities[J-03]

(2) Annotations to the Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities and its Interpretation[R-02]

(3) Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05]

-2. Of the support structures, with regards to the tower design, if there is an item which deviates from the content approved in the type certification, the result of design examination equivalent to that at the time of obtaining the type certification shall be shown for the deviating item.

-3. Of the support structures, if the tower was not included in the type certification, it is necessary at the time of the wind farm certification to separately carry out the evaluation items normally conducted at the time of type certification, such as a detailed evaluation of the connection between the tower and the wind turbine (RNA). Therefore, the handling of such items shall not be based on the provisions of these guidelines and instead shall be as separately deemed appropriate by ClassNK.

6.2 Support structure (Tower)

6.2.1 General

-1. In the design of the support structure (tower), if any item does not satisfy the provisions in 6.1.1-1., then it shall be shown that the item satisfies the required criteria regarding safety that are defined by the provisions in 6.1.1-1.

-2. In the case of -1. above, if the design is based on the method shown in Annex F, and it is confirmed by ClassNK that the contents of it are satisfied, then it may be considered that the required criteria regarding safety that are defined by the provisions in 6.1.1-1 are satisfied for the item.

6.3 Support structure (Foundation)

6.3.1 General

-1. In the design of the support structure (foundation), if any item does not satisfy the provisions in 6.1.1-1., then it shall be shown that the item satisfies the required criteria regarding safety that are defined by the provisions in 6.1.1-1.

6.3.2 Strength evaluation for support structure (foundation)

-1. Regarding the strength evaluation for the support structure (foundation), in addition to the regulations in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], attention shall also be paid to the following points.

(1) The bearing capacity of piles must be additionally evaluated by the formula prescribed in the Recommendations for Design of Building Foundations[R-06].

(2) The pile material properties (linear and nonlinear) and setting of the stress calculation method at the time of the pile stress examination must be appropriately considered.

(3) The horizontal resistance of piles must be additionally evaluated by a method using the group pile frame model specified in the Recommendations for Design of Building Foundations[R-06].

(4) When the response displacement method is used for the consideration, the combinations of the same direction and the opposite direction must be considered for each of the ground displacement and inertia force.

(5) When the occurrence of lateral flow is anticipated in an earthquake, the residual displacement of the foundation obtained from the result of its examination must be evaluated.

6.3.3 Items to be considered in the design

-1. Regarding the design for the support structure (foundation), in addition to the regulations in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], attention shall also be paid to the following points.

(1) When concrete foundation driving is carried out using a placing joint, the treatment method for it shall be specified in a drawing.

(2) If liquefaction is expected to occur, a note must be clearly indicated on the drawings to the effect that the clearance under the foundation, etc., should be checked after the occurrence of an earthquake, and that restoration measures should be taken if a clearance, etc., is found.

Annex A. Measurement data evaluation methods [normative]

A.1 Selection of measurement points

-1. The measurement points for the wind condition must be planned so that it is possible to obtain the necessary measurement data for all the wind turbines within a site.

-2. When determining the number of measurement points necessary, all wind turbines must be located within the representative radius of at least one measurement point, based on the assumption that the wind conditions at the wind turbine position will be estimated from airflow analysis, and on the idea that the uncertainty related to the estimation can be reduced if it is within the representative radius from the measurement point.

-3. The representative radius values shown in Table 2-1 are determined according to the topography, and are the values for when the ground surface roughness can be assumed to be uniform within the representative radius. It must be kept in mind that if the ground surface roughness is not uniform within the site or within the peripheral region set as the analysis region in the airflow analysis, then the representative radius may not be applicable in all directions, because the measured value at the measurement point may be affected by a ground surface roughness that is different from that at the wind turbine position. In this case, appropriate prior examination must be conducted, such as by carrying out airflow analysis during the stage of the selection of the measurement point.

-4. When measurement must be carried out in the vicinity of an existing wind turbine that is in operation, a point which is not affected by the wake of that wind turbine must be selected. If the separation distance from that wind turbine is 10D or more (D: Rotor diameter of the wind turbine in operation), the wind turbine may be treated as one that is not affected by the wake.

A.2 Wind speed measurement by measurement mast

-1. The wind speed measurement is carried out by using a cup type anemometer, or an anemometer of which the equivalent performance is guaranteed.

-2. The cup type anemometer is calibrated before the measurement period, and the calibration value is used in the wind condition evaluation. The calibration of the cup-type anemometer shall be performed in accordance with the procedure described in Annex F of JIS C 1400-12-1:2010[R-07] or in a procedure judged to be equivalent, and the calibration results shall be attached to the report.

-3. The cup type anemometer is installed at a position that is at least 2/3 of the hub height from the ground surface in order to reduce the uncertainty of the vertical extrapolation of the wind condition. When this is difficult, it becomes necessary to use measurement in combination with remote sensing equipment such as a vertical lidar, but even in this case, the cup type anemometer must be installed at the highest possible position. To evaluate the vertical profile of the wind shear at the planned site, two or more anemometers are added at intervals of about 10 m from the top anemometer. An anemometer may also be installed at a height close to the top anemometer for backup purposes.

-4. The installation of a wind speed anemometer on a measurement mast shall be in a manner that minimizes the effect on the anemometer from the mast and boom. It is desirable that the installation of a wind speed anemometer on a measurement mast follows Annex G of JIS C 1400-12-1:2010[R-07]. It is desirable that the boom installation is at an orientation that is 45° from the principal wind direction in the case of a cylindrical mast, and 90° from the principal wind direction in the case of a truss structure. When a lightning rod is installed, it is installed at a position where it will not affect the anemometer.

-5. The 10 minute average and standard deviation of the wind speed are measured. It is desirable that the sampling frequency is 1 Hz or higher. In addition, MEASNET[R-17], [A1] can be used as a reference for the calibration, installation method, equipment configuration, and test method, etc.

-6. If the planned site is in a cold region, a cold region specification device such as one with a heater must be used in order to maintain the response characteristics specified for anemometers.

A.3 Wind direction measurement by measurement mast

-1. The wind direction measurement is carried out by using a vane type anemometer. It is desirable to install one at each altitude to form pairs with the wind speed anemometers described in A.2. The installation of a wind direction anemometer on a measurement mast shall be in a manner that minimizes the effect on the anemometer from the mast and boom. It is desirable that the installation of a wind direction anemometer on a measurement mast follows Annex G of JIS C 1400-12-1:2010[R-07].

-2. The anemometer measures 10 minute averages. It is desirable that the sampling frequency is 1 Hz or higher.

A.4 Measurement using remote sensing devices

-1. When measurement is carried out by remote sensing equipment such as a vertical lidar, it is necessary to confirm the correlation with the measurement mast, so it is desirable to install the remote sensing equipment as close as possible to the measurement mast. However, since it is difficult to establish a general threshold value for the separation distance between the measurement mast and the remote sensing equipment, the placement of the equipment must be appropriately determined depending on the measurement mast guy lines and the surrounding conditions.

-2. For the measurement heights, the essential measurement heights shall be the height of the anemometer on the measurement mast with which the correlation is being confirmed, and the hub height of the planned wind turbine. Other heights shall be set appropriately, with one every 10 m as the standard setting.

-3. When the correlation between the measurement mast and the remote sensing equipment such as a vertical lidar is confirmed, it must be confirmed that the time stamp of the measurement mast data and the time stamps of the remote sensing equipment such as the vertical lidar agree.

A.5 Measurements and evaluation report of measurement results

-1. Reports on the measurements shall contain at least the following items.

(1) Site status:
- a. Photographs showing 360° around the measurement points, from all the measurement points
- b. Topographical map of the site showing the measurement points
- c. Separation distance between the measurement point and the planned wind turbine position
- d. Terrain judgment results for the measurement points and wind turbine positions (This may follow 2.2.3)

(2) Description of the measurement system:
- a. Specifications of measurement equipment and data collection systems (Including calibration certificates for measurement equipment)
- b. Arrangement of measurement equipment on the measurement mast and the confirmation results for it
- c. Drawings including the main dimensions of the measurement mast and mounting boom
- d. Method of maintaining anemometer calibration throughout the measurement period, and evidence to show that it was maintained

(3) Description of the measurement procedure:
- a. Description of the measurement procedure, test and inspection conditions, sampling rate, averaging time, measurement period
- b. Significant events that occurred during the entire measurement period (if any occurred)
- c. Data removal criteria applied during data analysis and conclusion derivation

-2. Reports on the evaluation of measurement results shall contain at least the following items.

(1) Long-term evaluation:
- a. Details of the methods used in the evaluation and the long-term data applied
- b. Results of statistical analysis with corrections using the long-term data applied
- c. Significance of the results of the long-term evaluation performed

(2) Wind direction and wind speed data:
- a. The average, maximum and minimum wind speeds and the wind speed standard deviations described in tabular form, for the entire duration of the measurements and for each month.
- b. The Weibull shape and scale factors for each direction, and the appearance frequency distribution and energy density distribution (with a wind direction sector width of 30° or less) for each direction specified in tabular form for each measurement mast. A wind direction distribution map (plot) is also required.
- c. When a measurement mast and remote sensing equipment are being used together, a correlation diagram showing the result of confirmation of the required values related to the correlation as shown in Table 2-2, and parameters representing the regression line.
- d. When the required values shown in Table 2-2 are not satisfied in c. above, the results of consideration of the reason why the required values were not satisfied, following the notes shown in Table 2-2.

(3) Turbulence intensity:
- a. The ambient turbulence intensity for each direction (with a wind direction sector width of 30° or less) specified in tabular form for each measurement mast.
- b. Chart comparing the ambient turbulence intensity and IEC turbulence category with consideration of all wind directions.

(4) Temperature:
  a. The average value, minimum value, and maximum value of the temperature described in tabular form, for the entire duration of the measurements and for each month.

(5) Atmospheric pressure:
  a. The average value, minimum value, and maximum value of the atmospheric pressure described in tabular form, for the entire duration of the measurements and for each month.

(6) Humidity:
  a. The average value, minimum value, and maximum value of the relative humidity described in tabular form, for the entire duration of the measurements and for each month.

A.6 Reference documents

[A1] MEASNET, JWPA translation, Evaluation of Site Wind Conditions (Japanese version) (Original title: Evaluation of Site Specific Wind Conditions. Version 1), 2016.

Annex B. Airflow analysis and verification of its validity [normative]

B.1 Airflow analysis

B.1.1 Topographic data and ground surface roughness data

-1. Use the topographic data (numerical elevation data) and ground surface roughness data from around the planned site as input data for the airflow analysis. Reproduce the surrounding terrain with high accuracy for as wide a range as possible.
-2. Topographic data shall not have a resolution greater than 50 m. In the case of complex terrain, it is desirable to use data with a high resolution, but it must be appropriately considered together with the setting of the calculation grid prescribed in B.1.3.
-3. Ground surface roughness data shall not have a resolution greater than 100 m. When the change in the distribution of ground surface roughness is large, it is desirable to use data with a higher resolution. For the topographic data and ground surface roughness data, it is possible to use the digital national land information and basic map information from the Geospatial Information Authority of Japan.

B.1.2 Calculation region

-1. The calculation region must be set as the range of the planned site, that is, the range including the measurement masts and all wind turbines. The distance from the measurement masts and all wind turbines to the calculation region boundary (inflow plane, outflow plane, side plane) must be 20 times or more the hub height. In addition, it is desirable to set an additional region for the flow to enter and exit smoothly (including on the side plane). When the flow cannot be set to flow smoothly in and out, it is also necessary to take a sufficiently long distance.
-2. For the distance to the inflow boundary, in addition to being more than 20 times the hub height as written above, the changes in the terrain (elevation) in all directions around the planned site should be evaluated and the effect of the terrain on the upwind side must be taken into consideration in the distance. An example of a calculation region is shown in Figure B.1.
-3. For the upper air region, the ratio (blockage ratio) of the cross section of the reproduced terrain to the cross section of the analysis region, which is decided by the lateral range and the vertical range, must be 5% or less in order to avoid the overestimation of the wind speed above the terrain due to a blockage effect. Or else, a height that is at least 20 times the maximum difference in elevation must be secured in the vertical direction. If it is difficult to do so, the evidence must be provided.

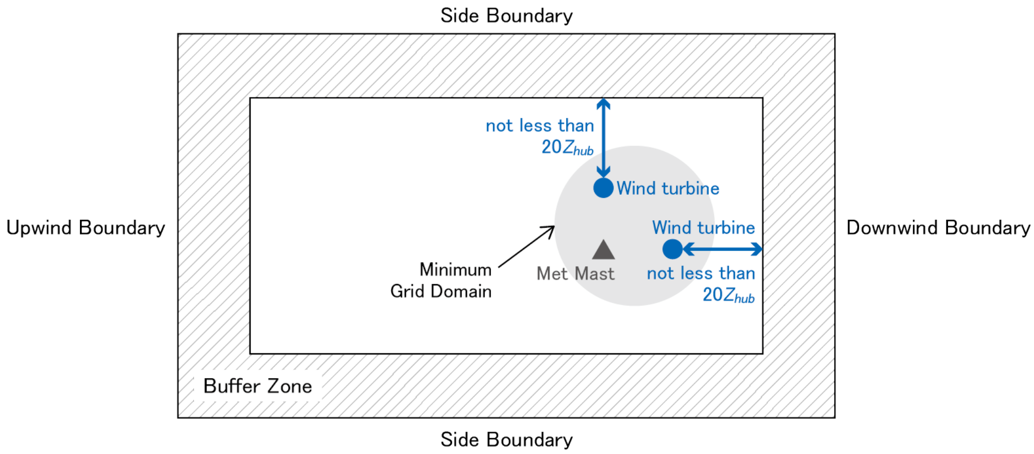

Figure B.1 Example of calculation region (Horizontal direction)

B.1.3 Calculation grid and resolution

-1. In principle, the calculation grid size in the horizontal direction of the range that includes the measurement masts and wind turbines (the minimum grid range) shall not exceed 25 m. It is possible to use a gradually rougher grid as the distance from the minimum grid range increases, but in that case, the elongation rate of the calculation grid size must be 1.2 or less.

-2. For the calculation grid resolution in the vertical direction, in the case of the *k-epsilon* model, the first calculation grid point on the ground surface is set in a region where the average wind speed distribution can be approximated by a logarithmic or power law, that is, around the roughness length, and then the grid resolution may be made gradually coarser with increased elevation. In this case, the elongation rate of the calculation grid width must be 1.2 or less.

B.1.4 Boundary conditions

-1. For the inflow boundary conditions, set the vertical distribution of the average speed and turbulence statistics, based on the ground surface roughness at the inflow point. For the outflow boundary conditions, use either a free outflow condition or convective outflow condition in order to avoid the generation of unnatural flow from the outflow boundary. For the lateral boundary conditions and upper boundary conditions, use slip conditions.

-2. For the ground surface boundary conditions, in the case of the *k-epsilon* model, use a wall function using the ground surface roughness parameter.

B.1.5 Direction division

-1. The direction division must be set appropriately according to the complexity of the terrain.

-2. There must be 12 or more directions for flat terrain and 16 or more directions for complex terrain. If it is difficult to do so, the evidence for that must be provided appropriately.

B.2 Verification of airflow analysis validity

B.2.1 Verification of validity of airflow analysis applied to the calculation of wind conditions during power production

-1. To verify the validity of the airflow analysis applied to the calculation of the wind conditions during power production, use the airflow analysis to calculate at least the following items for the measurement mast position and then compare the results with the measurement data.

(1) Average wind speed by wind direction

(2) Vertical profiles of wind shear by wind direction

(3) Turbulence intensity by wind direction

-2. For the average wind speed by wind direction, when there are multiple measurement masts, they must be mutually combined for the comparison of the measurement data and the airflow analysis results. When there is only one measurement mast, the comparison should be made using measurement data at a height different from the height used as input data for the airflow analysis.

-3. The vertical profiles of the wind shear by wind direction are normalized by the wind speed at the highest point on the measurement mast, and then the comparison of the measurement data with the airflow analysis results must be conducted in a format following the example shown in Figure B.2. However, if there is measurement data by a vertical lidar, it should be normalized by the wind speed at hub height in a format following the example shown in Figure B.3.

-4. With regard to the turbulence intensity by wind direction, use the turbulence energy *k* of the *k-epsilon* model, etc., in the airflow analysis and obtain the standard deviation of the wind speed fluctuation in the principal wind direction that arises due to the terrain and surface roughness σ_u^{surf} by using equation (B.1). Also, the wind speed U obtained from the airflow analysis and equation (B.2) must be used to calculate I_{sim} and then compare the result with the turbulence intensity obtained from measurement data. In this case, in principle, the wind speed bin corresponding to 15 m/s shall be applied, but the wind speed bin may be changed depending on the measurement data (the number of measurement points per wind speed bin, etc.).

$$\sigma_u^{surf} = \sqrt{1.2k} \tag{B.1}$$

$$I_{sim} = \frac{\sigma_u^{surf}}{U} \tag{B.2}$$

B.2.2 Verification of validity of airflow analysis applied to the wind conditions during parked by storm

-1. To verify the validity of the airflow analysis applied to the calculation of the wind conditions during parked by storm, use the airflow analysis to calculate at least the following items for the measurement mast position and then compare the results with the measurement data. For the details of each item, the provisions of B.2.1 shall apply.

(1) Average wind speed by wind direction

(2) Vertical profiles of wind shear by wind direction

(3) Turbulence intensity by wind direction

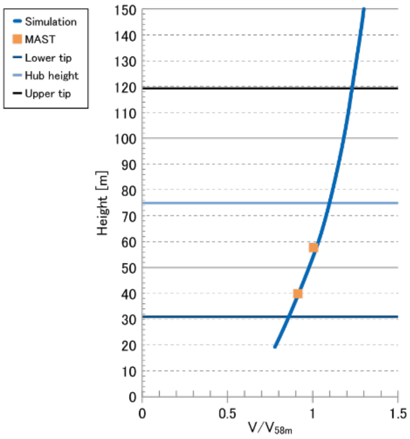

Figure B.2 Measurement mast only

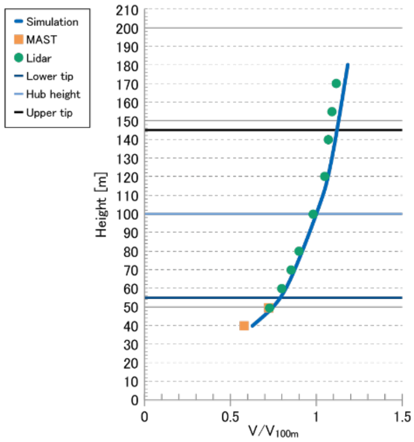

Figure B.3 Measurement mast + vertical lidar

B.3 Report on airflow analysis and its validity

B.3.1 Report on the airflow analysis applied to the wind conditions during power production and its validity

-1. Reports on the airflow analysis applied to the calculation of the wind conditions during power production and on the verification of the validity of that analysis shall include at least the following items.

(1) Details of the airflow analysis (including the following content):

a. Topographical map with grid information

b. Roughness map and roughness length definition

c. CFD simulation settings

1) Software

2) Applied model

3) Analysis region definition

4) Horizontal grid size:

- Area corresponding to the minimum grid size
- Rate of elongation
- Maximum grid size
- Figures containing the above items

5) Vertical grid size:

- Minimum grid size
- Rate of elongation
- Figures containing the above items

(2) Results of validity verification (including the following content):

a. Results of comparison of the airflow analysis with the measurement data regarding the average wind speed by wind direction

b. Results of comparison of the airflow analysis with the measurement data regarding the vertical profiles of wind shear by wind direction

c. Results of comparison of the airflow analysis with the measurement data regarding the turbulence intensity by wind direction

B.3.2 Report on the airflow analysis applied to the wind conditions during parked by storm and its validity

-1. Reports on the airflow analysis applied to the calculation of the wind conditions during parked by storm and on the verification of the validity of that analysis shall include at least the following items.

(1) Details of the airflow analysis (including the following content):

a. Topographical map with grid information

b. Roughness map and roughness length definition

c. CFD simulation settings

1) Software

2) Applied model

3) Analysis region definition

4) Horizontal grid size:

- Area corresponding to the minimum grid size
- Rate of elongation
- Maximum grid size
- Figures containing the above items

5) Vertical grid size:

- Minimum grid size
- Rate of elongation
- Figures containing the above items

(3) Results of validity verification (including the following content):

a. Results of comparison of the airflow analysis with the measurement data regarding the average wind speed by wind direction

b. Results of comparison of the airflow analysis with the measurement data regarding the vertical profiles of wind shear by wind direction

c. Results of comparison of the airflow analysis with the measurement data regarding the turbulence intensity by wind direction

Annex C. Evaluation method for wind conditions [informative / normative]

C.1 General

-1. The calculation method for the wind conditions during power production that is shown in C.2 is shown as a reference. This does not deny any method that is not based on these rules.

-2. The calculation method for the wind conditions during parked by storm that are shown in C.3.1 and C.3.2 are based on the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and not following this rule is not permitted.

C.2 Wind conditions during power production

C.2.1 Wind speed appearance frequency distribution and average wind speed

-1. The wind speed appearance frequency distribution function $p(V_{\mathrm{hub}})$ shall be approximated by the Weibull distribution expressed by equation (C.1).

$$p(V_{\mathrm{hub}}) = \frac{m}{\eta}\left(\frac{V_{hub}}{\eta}\right)^{m-1} exp\left\{-\left(\frac{V_{hub}}{\eta}\right)^{m}\right\} \tag{C.1}$$

Here, η and m are the scale factor and shape factor of the Weibull distribution, respectively, and are obtained from the average wind speed V_{ave} and average wind speed standard deviation σ_{v} obtained from measurement by using by equations (C.2) and (C.3).

$$\int_0^{\infty} \frac{m}{\eta}\left(\frac{V_{hub}}{\eta}\right)^{m-1} exp\left\{-\left(\frac{V_{hub}}{\eta}\right)^{m}\right\} V_{hub} dV_{hub} = V_{ave} \tag{C.2}$$

$$\int_0^{\infty} \frac{m}{\eta}\left(\frac{V_{hub}}{\eta}\right)^{m-1} exp\left\{-\left(\frac{V_{hub}}{\eta}\right)^{m}\right\} (V_{hub} - V_{ave}) dV_{hub} = \sigma_V^2 \tag{C.3}$$

-2. The time series data $U_R(x, y, H_h, \theta, t)$ of the average wind speed at wind turbine position and hub height are obtained by using equation (C.4).

$$U_R(x, y, H_h, \theta, t) = U_M(h, \theta, t) \cdot C_V(x, y, H_h, \theta) \tag{C.4}$$

Where:

$U_M(h, \theta, t)$	:	Time series data of wind speed obtained from measurement data at the measurement mast position and measurement height
$C_V(x, y, H_h, \theta)$	:	The wind speed ratio found from the wind speed $u_T(x, y, H_h, \theta)$ in the wind direction θ at the wind turbine position and hub height found using airflow analysis and the wind speed $u_M(x, y, h, \theta)$ in wind direction θ at measurement mast position and measurement height found using airflow analysis, which is found from the following equation [$= u_T(x, y, H_h, \theta)/u_M(x, y, h, \theta)$]

-3. The average wind speed in each direction at the wind turbine position and hub height $V_{ave}\,(x, y, H_h, \theta)$ is obtained by using equation (C.5).

$$V_{ave}\,(x, y, H_h, \theta) = \frac{\sum_{i=1}^{N} U_R(x, y, H_h, \theta, t)}{N} \tag{C.5}$$

Where:

N	:	Number of measurement data included in the relevant direction (Number of items in time series data)

C.2.2 Calculation method for turbulence intensity

-1. The time series data $\sigma_R(x, y, H_h, \theta, t)$ of the ambient turbulence standard deviation at the wind turbine position and hub height is obtained by using equation (C.6).

$$\sigma_R(x, y, H_h, \theta, t) = \sigma_M(h, \theta, t) \cdot C_S(x, y, H_h, \theta) \tag{C.6}$$

Where:

$\sigma_M(h,\theta,t)$	:	Time series data of ambient turbulence standard deviation obtained from measurement data at the measurement mast position and measurement height
$C_S(x,y,H_h,\theta)$	:	Ambient turbulence standard deviation in wind direction θ at wind turbine position and hub height from airflow analysis As $\sigma_T(x,y,H_h,\theta)$, the wind speed ratio found from the ambient turbulence standard deviation $\sigma_M(x,y,h,\theta)$ in wind direction θ at the measurement mast position and the measurement height found using airflow analysis, which is found from the following equation $[=\sigma_T(x,y,H_h,\theta)/\sigma_M(x,y,h,\theta)]$

-2. The turbulence intensity $I_{rep}(x,y,H_h,\theta,V_i)$ representing the direction θ and the ith wind speed bin at the wind turbine position and hub height is the 90% quantile of the ambient turbulence standard deviation and is obtained by using equation (C.7).

$$I_{rep}(x,y,H_h,\theta,V_i)=\frac{\sigma(x,y,H_h,\theta,V_i)+1.28\sigma_\sigma(x,y,H_h,\theta,V_i)}{V_i\,(x,y,H_h,\theta)} \tag{C.7}$$

Where:

$\sigma(x,y,H_h,\theta,V_i)$	:	Ambient turbulence standard deviation at direction θ and i^{th} wind speed bin
$\sigma_\sigma(x,y,H_h,\theta,V_i)$	:	Standard deviation of the ambient turbulence standard deviation at direction θ and i^{th} wind speed bin
$V_i\,(x,y,H_h,\theta)$	:	Wind speed representative of the i^{th} wind speed bin in the direction θ

-3. The turbulence intensity $\overline{I_{rep,i}}$ representing the ith wind speed bin representing all directions is weighted and averaged using the wind speed appearance frequency in each direction and obtained by using equation (C.8).

$$\overline{I_{rep,i}}=\sum_\theta\left(I_{rep}(x,y,H_h,\theta,V_i)F(\theta)\right) \tag{C.8}$$

Where:

$F(\theta)$	:	Wind speed appearance frequency or energy density in direction θ

C.2.3 Calculation method for wind shear exponent

-1. The wind shear exponent for each direction at the wind turbine position and hub height $\alpha(x,y,H_h,\theta)$ shall be obtained by using the least squares method with the average wind speed of each direction θ at the top of the rotor plane, the hub height and the bottom of the rotor plane. This can also be calculated by using equation (C.9), but it is preferable to handle that value as a reference.

$$\alpha(x,y,H_h,\theta)=\frac{\ln\left(\dfrac{V_U(x,y,H_U,\theta)}{V_L(x,y,H_L,\theta)}\right)}{\ln\left(\dfrac{H_U-d}{H_L-d}\right)} \tag{C.9}$$

Where:

$V_U(x,y,H_U,\theta)$	:	Average wind speed at the top of the rotor plane at the wind turbine position in direction θ
$V_L(x,y,H_L,\theta)$	:	Average wind speed at the bottom of the rotor plane at the wind turbine position in direction θ
H_U	:	Height of the top of the rotor plane
H_L	:	Height of the bottom of the rotor plane
d	:	Zero plane displacement (displacement height)

-2. The wind shear exponent representing all directions $\overline{\alpha}$ is weighted and averaged using the wind speed appearance frequency in each direction and obtained by using equation (C.10).

$$\overline{\alpha} = \sum_{\theta} \left(\alpha(x, y, H_h, \theta) F(\theta) \right) \tag{C.10}$$

Where:

$F(\theta)$: Wind speed appearance frequency or energy density in direction θ

C.2.4 Calculation method for inflow angle

-1. The inflow angle in each direction at the wind turbine position and hub height $\varphi(x, y, H_h, \theta)$ is obtained by using equation (C.11).

$$\varphi(x, y, H_h, \theta) = tan^{-1} \left(\frac{u_{T3}(x, y, H_h, \theta)}{\sqrt{\left(u_{T1}(x, y, H_h, \theta)\right)^2 + \left(u_{T2}(x, y, H_h, \theta)\right)^2}} \right) \tag{C.11}$$

Where:

$u_{T1}(x, y, H_h, \theta)$: Longitudinal component of the wind speed in wind direction θ at wind turbine position and hub height from airflow analysis

$u_{T2}(x, y, H_h, \theta)$: Lateral component of the wind speed in wind direction θ at wind turbine position and hub height from airflow analysis

$u_{T3}(x, y, H_h, \theta)$: Vertical component of the wind speed in wind direction θ at wind turbine position and hub height from airflow analysis

-2. The inflow angle representing all directions $\overline{\varphi}$ is weighted and averaged using the wind speed appearance frequency in each direction and obtained by using equation (C.12).

$$\overline{\varphi} = \sum_{\theta} \left(\varphi(x, y, H_h, \theta) F(\theta) \right) \tag{C.12}$$

Where:

$F(\theta)$: Wind speed appearance frequency or energy density in direction θ

C.2.5 Calculation method for atmospheric density

-1. The atmospheric density is calculated from the atmospheric temperature and atmospheric pressure observed at the site by using the equation (C.13).

$$\rho = \frac{B}{T \times R_0} \tag{C.13}$$

Where:

B : Atmospheric pressure

T : Atmospheric temperature

R_0 : Gas constant (287.05 $[J/kgK]$)

-2. When there is no measurement data regarding the atmospheric density at the site, there are cases in which the long-term measurement data from a nearby meteorological observatory can be applied by carrying out altitude correction regarding the elevation. However, in this case, the basis for the applicability of the data shall be clearly stated.

C.3 Wind conditions during parked by storm

C.3.1 Calculation method for extreme wind speed (10 minutes average wind speed with a return period of 50 years)

-1. The 10 minutes average wind speed with a return period of 50 years at wind turbine position and hub height U_h shall be obtained by multiplying the reference wind speed V_0 by the topographic multiplier for the average wind speed E_{tV} and the altitude correction coefficient E_{pV} and is determined by equation (C.14). However, the reference wind speed V_0 shall be the 10 minutes average wind speed with a return period of 50 years at a height of 10 m above flat ground that has a ground surface roughness classification of II, and the reference wind speed used shall be that shown per municipality in No. 2 of the Ministry of Construction Notification No. 1454 in 2000.

$$U_h = E_{tV} E_{pV} V_0 \tag{C.14}$$

-2. The ground surface roughness classification at the wind turbine position is determined according to the Building Standards Act or by the situation of the ground surface around the wind power generation facility support according to Table C.1.

Table C.1 Categorization of ground surface roughness classifications

Roughness class	Ground surface conditions around the construction site
I	Areas with few obstacles, such as the surface of a sea or lake
II	Areas where the obstacles are only around the level of farm products, such as pastoral areas and grasslands, areas where trees and low-rise buildings, etc., are scattered
III	Areas with many trees and low-rise buildings, or areas where medium-rise buildings (4 to 9 floors) are scattered
IV	Urban areas mainly consisting of medium-rise buildings

-3. The altitude correction coefficient E_{pV} for the average wind speed at hub height above flat terrain is calculated according to the ground surface roughness classification by using equation (C.15). Here, H_h is the hub height (m), and Z_b, Z_G and α are parameters indicating the vertical distribution of wind speed and are defined by Table C.2 according to the ground surface roughness classification. The altitude correction coefficient for the average wind speed at height Z is obtained by substituting Z for H_h in equation (C.15).

$$E_{pV} = \begin{cases} 1.7\left(\dfrac{H_h}{Z_G}\right)^{\alpha} & Z_b < H_h \le Z_G \\ 1.7\left(\dfrac{Z_b}{Z_G}\right)^{\alpha} & H_h \le Z_b \end{cases} \tag{C.15}$$

Table C.2 Parameters to determine the altitude correction coefficient for average wind speed

Roughness class	I	II	III	IV
Z_b	5	5	10	20
Z_G	250	350	450	550
α	0.1	0.15	0.2	0.27

-4. The topographic multiplier for the average wind speed E_{tV} and the wind direction to be verified θ_d are determined by either of the following methods (1) and (2).

(1) Method that does not consider the wind directional characteristics
The topographic multiplier for the average wind speed E_{tV} is decided by the equation (C.16) based on the results of airflow analysis by wind direction on the actual terrain and on flat terrain. Here, $U\,(x,\ y,\ H_h,\ \theta)$ is the average wind speed obtained by airflow analysis for wind direction θ at the wind turbine position and hub height H_h on the actual terrain, and $U^P(x,\ y,\ H_h)$ is the average wind speed at the hub height H_h at the wind turbine construction site that was

obtained by airflow analysis for flat terrain of ground surface roughness classification P. In addition, the wind direction to be verified θ_d shall be the wind direction where the multiplier for the wind speed per wind direction is the largest.

$$E_{tV} = max(E'_{tV},\ 1)\,,\qquad E'_{tV} = \max_{\theta}\left(\frac{U\ (x,\ y,\ H_h,\ \theta)}{U^P(x,\ y,\ H_h)}\right) \tag{C.16}$$

(2) Method that considers the wind directional characteristics
The topographic multiplier for the average wind speed E_{tV} is decided by the equation (C.17) based on the results of typhoon simulations for the wind turbine construction site. Here, $U_{50}(x,\ y,\ H_h)$ is the expected annual maximum wind speed with a return period of 50 years at the hub height H_h at the wind turbine construction site, which is obtained by statistical analysis from the result of the typhoon simulation, and $U^P_{50}(x,\ y,\ H_h)$ is the expected annual maximum wind speed with a return period of 50 years at the hub height above flat terrain of the ground surface roughness classification. In addition, the wind direction to be verified θ_d shall be the wind direction corresponding to $U_{50}(x,\ y,\ H_h)$. Furthermore, it must be sufficiently confirmed that there is no problem with the application of the typhoon simulation by conducting a comparison with measurement values, etc., in addition to checking the validity of the simulation itself.

$$E_{tV} = max(E'_{tV},\ 1)\,,\qquad E'_{tV} = \frac{U_{50}(x,\ y,\ H_h)}{U^P_{50}(x,\ y,\ H_h)} \tag{C.17}$$

C.3.2 Calculation method for extreme wind speed (3 seconds average wind speed)

C.3.2.1 Calculation method for turbulence intensity

-1. The principal wind direction component of the turbulence intensity during a storm at the wind turbine position I_{h1} shall be obtained by multiplying the turbulence intensity on flat terrain I_P by the correction coefficient for the turbulence intensity due to the terrain E_{tI} and is obtained by using equation (C.18).

$$I_{h1} = E_{tI} I_P \tag{C.18}$$

-2. The turbulence intensity at hub height on flat terrain I_P is calculated according to the ground surface roughness classification by using equation (C.17). Here, H_h is the hub height (m), and Z_b, Z_G and α are parameters indicating the vertical distribution of wind speed and are defined by Table C.2 according to the ground surface roughness classification. The turbulence intensity at height Z is obtained by substituting Z for H_h in equation (C.19).

$$I_P = \begin{cases} 0.1\left(\dfrac{H_h}{Z_G}\right)^{-\alpha-0.05} & Z_b < H_h \le Z_G \\ 0.1\left(\dfrac{Z_b}{Z_G}\right)^{-\alpha-0.05} & H_h \le Z_b \end{cases} \tag{C.19}$$

-3. The correction coefficient for the turbulence intensity due to the terrain E_{tI} is determined by the equation (C.20). Here, the topographic multiplier for the average wind speed E'_{tV} is obtained by using equation (C.21) based on the results of airflow analysis by wind direction on the actual terrain and on flat terrain. Here, $U\ (x, y, H_h, \theta)$ is the average wind speed obtained by airflow analysis for wind direction θ at hub height H_h at the wind turbine construction site on the actual terrain, and $U^P(x, y, H_h)$ is the average wind speed at the hub height H_h at the wind turbine construction site that was obtained by airflow analysis for flat terrain of ground surface roughness classification P.

$$E_{tI} = max(E_{tS}/E'_{tV}\,,\ 1) \tag{C.20}$$

$$E'_{tV} = \max_{\theta}\left(\frac{U\ (x, y, H_h, \theta)}{U^P(x, y, H_h)}\right) \tag{C.21}$$

-4. The correction coefficient for the fluctuating wind speed due to the terrain E_{tS} is determined by the equation (C.22). Here,

$\sigma_u(x,y,H_h,\theta_d)$ is the standard deviation of the wind speed fluctuation in the principal wind direction at the hub height H_h in the wind direction to be verified on the actual terrain θ_d, and $\sigma_u^P(x,y,H_h)$ is the standard deviation of the wind speed fluctuation in the principal wind direction at the hub height H_h on flat terrain with a ground surface roughness classification P, which are obtained from airflow analysis.

$$E_{tS} = \frac{\sigma_u(x,y,H_h,\theta_d)}{\sigma_u^P(x,y,H_h)} \quad (C.22)$$

-5. In order to obtain the standard deviation of the wind speed fluctuation in the principal wind direction σ_u from airflow analysis, it is also possible to calculate it by using equation (C.24) after using equation (C.23) to calculate the standard deviation of the wind speed fluctuation in the principal wind direction caused by the terrain and the surface roughness σ_u^{surf} from the turbulent flow energy *k* in the *k-epsilon* model, etc. However, in this case, the background turbulence intensity I_a shall be 0.1.

$$\sigma_u^{surf} = \sqrt{1.2k} \quad (C.23)$$

$$\sigma_u = U \times \sqrt{\left(\frac{\sigma_u^{surf}}{U}\right)^2 + I_a^2} \quad (C.24)$$

C.3.2.2 Calculation method for 3 seconds average wind speed

-1. The extreme 3 seconds average wind speed at hub height with a return period of 50 years U_{e50} is calculated by equation (C.25) by using the U_h calculated using equation (C.14).

$$U_{e50} = G_f U_h \quad (C.25)$$

Where:

$G_f = 1 + 3.5 I_{h1}$

*Reference: In IEC61400-1:2019[J-02], $G_f \fallingdotseq 1.4$ is used as $I_{h1} = 0.11$.

C.3.2.3 Calculation method for wind shear for extreme wind speed

-1. The wind shear exponent $\alpha(x,y,H_h,\theta_d)$ corresponding to the 10 minutes average wind speed with a return period of 50 years at wind turbine position and hub height U_h, is obtained by the least squares method using the horizontal wind speed with consideration of the principal flow direction component U_1 and the principal flow direction perpendicular component U_2 at the following three heights at wind turbine position and wind direction to be checked θ_d of hub height, which is obtained from airflow analysis.

(1) Horizontal wind speed at the top of the rotor plane :$U_U(x,y,H_U,\theta_d) = \sqrt{\left(U_1(x,y,H_U,\theta_d)\right)^2 + \left(U_2(x,y,H_U,\theta_d)\right)^2}$

(2) Horizontal wind speed at hub height :$U_h(x,y,H_h,\theta_d) = \sqrt{\left(U_1(x,y,H_h,\theta_d)\right)^2 + \left(U_2(x,y,H_h,\theta_d)\right)^2}$

(3) Horizontal wind speed at the bottom of the rotor plane :$U_L(x,y,H_L,\theta_d) = \sqrt{\left(U_1(x,y,H_L,\theta_d)\right)^2 + \left(U_2(x,y,H_L,\theta_d)\right)^2}$

C.3.3 Calculation method for U_{e50} using wind condition measurement data [informative]

-1. The method to use measurement data to calculate the turbulence intensity I_{h1} during a parked by storm and find U_{e50} is shown below.

(1) Use airflow analysis to calculate the ratio of the wind speed and the ratio of the turbulence standard deviation between the measurement position and each wind turbine position for each direction.

(2) Create time series data for the wind speed and turbulence standard deviation at the wind turbine position by multiplying

measurement data (10 minutes value time series data) which satisfies the provisions of 2.2.1 by the ratio obtained in (1).

(3) When the method that does not consider the wind directional characteristics in C.3.1-4. (1) is used in the calculation of the 10 minutes average wind speed at hub height with a return period of 50 years (U_h), calculate the turbulence intensity by wind speed bin with consideration of all wind directions. When the method that considers the wind directional characteristics in C.3.1-4. (2) is used, calculate the turbulence intensity by wind speed class for each wind direction.

(4) For the turbulence intensity by wind speed class created in (3), calculate the turbulence intensity corresponding to the 50% quantile (non-exceedance probability of 50%) for each wind speed class, and calculate $I_{h1,meas}$ from the turbulence intensity value corresponding to the 50% quantile (non-exceedance probability of 50%) in the range that is not less than half the wind speed of V_0 at the site.

- For the calculation of $I_{h1,meas}$, the specific calculation method such as whether to use the average value or the maximum value, etc., of the turbulence intensity corresponding to the 50% quantile (probability of non-exceedance 50%) in the range that is not less than half the wind speed of V_0 shall be selected according to the trends in the measurement data, with selection so that it is on the safe side.
- When the method that considers the wind directional characteristics in C.3.1-4. (2) is used in the calculation of U_h, it should be noted that it is necessary to calculate $I_{h1,meas}$ using the turbulence intensity by wind speed class in the wind direction to be verified θ_d, and that the number of measurement data in the wind direction must be sufficient, including the data in the high wind speed region.

(5) Use whichever is the larger of the $I_{h1,meas}$ obtained in (4) and the turbulence intensity above flat terrain according to the ground surface roughness classification I_p as I_{h1} and use equation (C.25) to calculate U_{e50}.

-2. In order to show the validity of the turbulence intensity during a storm I_{h1} that was calculated using measurement data, a figure must be prepared which is a plot of the turbulence intensity values used in the calculation and also includes a plot showing the 50% quantile (non-exceedance probability of 50%) of the turbulence intensity by each wind speed class, a line showing the values of I_p and a line showing the values of $I_{h1,meas}$.

C.4 Reports on wind conditions

C.4.1 Report on wind conditions during power production

-1. Reports on the wind conditions during power production shall include at least the following items for all wind turbine positions and hub heights.

(1) Average wind speed (including the following content):

a. The Weibull shape and scale factors for each direction, and the wind direction appearance frequency distribution (with a wind direction sector width of 30° or less and the first sector centered on true north) specified in tabular form for each wind turbine position (hub height).

b. Or else, the detailed appearance rate distribution (according to the bin method; wind speed bin width of 1 m/s, wind direction sector width of 30° or less, and first sector centered on true north) described in tabular form for each wind turbine hub height position.

(2) Turbulence intensity (including the following content):

a. The turbulence intensity at the wind turbine position hub height described in tabular form for each wind speed bin (bin width 1 m/s or less) and wind direction bin (bin width 30° or less). Also describe the characteristic value/representative value of turbulence intensity applied to the design specified in the type certification for the planned wind turbine.

(3) Wind shear exponent (including the following content):

a. The average value, minimum value, and maximum value of the wind shear exponent in the wind turbine position, described in tabular form with a wind direction sector width of 30° or less.

(4) Flow inclination angle (including the following content):

a. The average value, minimum value, and maximum value of the estimated value of the average flow inclination angle at the wind turbine position at hub height, described in tabular form with a wind direction sector width of 30° or less.

C.4.2 Report on wind conditions during parked by storm

-1. Reports on the airflow analysis applied to the calculation of the wind conditions during parked by storm and on the verification of the validity of that analysis shall include at least the following items for all wind turbine positions and hub heights.

(1) 10 minutes average wind speed: U_h
(2) Turbulence intensity: I_{h1}
(3) 3 seconds average wind speed: U_{e50}
(4) Wind shear exponent

-2. For the parameters defined in this Annex that are used for the calculation of each of the values in -1 above, all of the values by direction shall be shown, and it must be possible to appropriately confirm the setting of the wind direction to be verified and its calculation process.

-3. When calculating U_{e50} using wind condition measurement data, it must be possible to appropriately confirm the basis for the I_{h1} calculation, including the figures specified in C3.3-2.

C.4.3 Other conditions

-1. The following conditions must be included.

(1) Site temperature range based on field measurements, etc.
(2) Site humidity range based on field measurements, etc.

C.5 Reference documents

[C1] JIS W 0201: 1990 : Standard atmosphere

[C2] Ishihara, T. and Yamaguchi, A., Prediction of the extreme wind speed in mixed climate region by using Monte Carlo simulation and Measure-Correlate-Predict method, Wind Energy, 2014.

[C3] Ueda et al., Validation of Evaluation Method of Turbulence Intensity by CFD with field measurements, proceedings of the 37th Wind Energy Symposium, pp. 245-246, 2015.

Annex D. Equivalent wind pressure coefficient for the nacelle cover [informative]

D.1 General

-1. The equivalent wind pressure coefficient for the nacelle cover varies greatly depending on the shape of the nacelle cover. This Annex shows the equivalent wind pressure coefficient (positive/negative) for a rectangular nacelle cover with rounded corners.

-2. In the calculation of the equivalent maximum/minimum wind pressure coefficient for this rectangular nacelle cover with rounded corners, wind tunnel tests have been carried out under the test conditions shown in Table D.1.

Table D.1 Main conditions for wind tunnel tests

Wind tunnel measurement section	W: 3.1 m × H: 2.0 m × L: 16.0 m
Model position	14.75 m from the upstream end of the measurement tunnel
Average wind speed	10.0 m/s (Hub height)
Turbulence intensity	12.7% (Hub height)
Vertical profile of wind speed	0.2 (Hub height center)
Test wind direction	72 wind directions with 5° pitch
Model (Scale 1/50)	• Nacelle: 250 x 80 x 80 (mm) • Tower: 60 φ (mm) *A photograph of the model is shown in Figure D-1.
Hub height	Height above wind tunnel floor: 400 mm
Pressure measurement holes	200 points (with consideration of symmetry)
Sampling	800 Hz, moving average processing for 6 items
Data length	60 seconds (Equivalent to 600 seconds real time)
Data count	1 sample (60 seconds) with 5 samples

a) Wind tunnel test model

b) Installation of turbulent boundary layer generator

Figure D.1 Wind tunnel test model

D.2 Equivalent wind pressure coefficient [Wind direction: -15° to +15°]

-1. The equivalent wind pressure coefficient [positive value] and the equivalent wind pressure coefficient [negative value] obtained from the wind tunnel test results in the range of -15° to +15°, which are the wind directions to be considered in DLC6.1, are shown in Figure D.2 and D.3, respectively.

-2. The equivalent wind pressure coefficient [positive value] shown in Figure D.2 corresponds to the "$\hat{C}_{em}$ - Positive value" applied to NC.1-1 in Table 5-2, and the equivalent wind pressure coefficient [negative value] shown in Figure D.3 corresponds to the "$\hat{C}_{em}$ - Negative value" applied to NC.1-2 in Table 5-2.

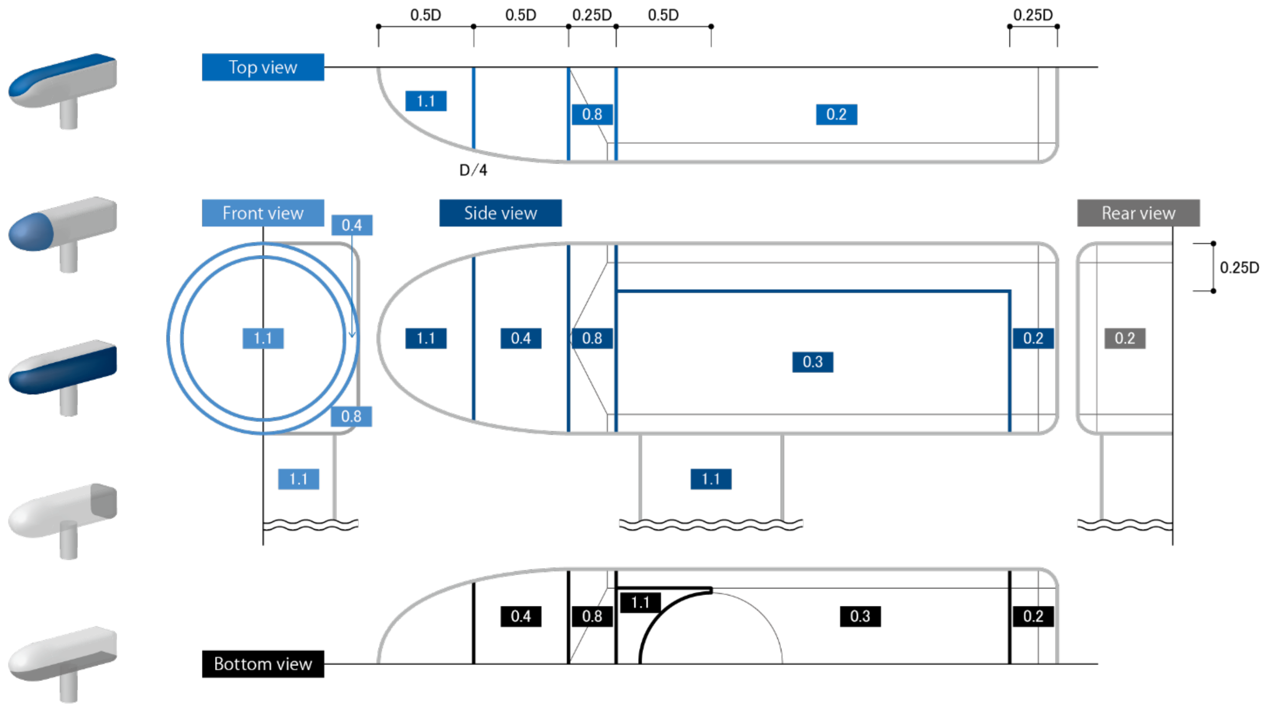

Figure D.2 Equivalent wind pressure coefficient [Wind direction: -15° to +15° - Positive value]

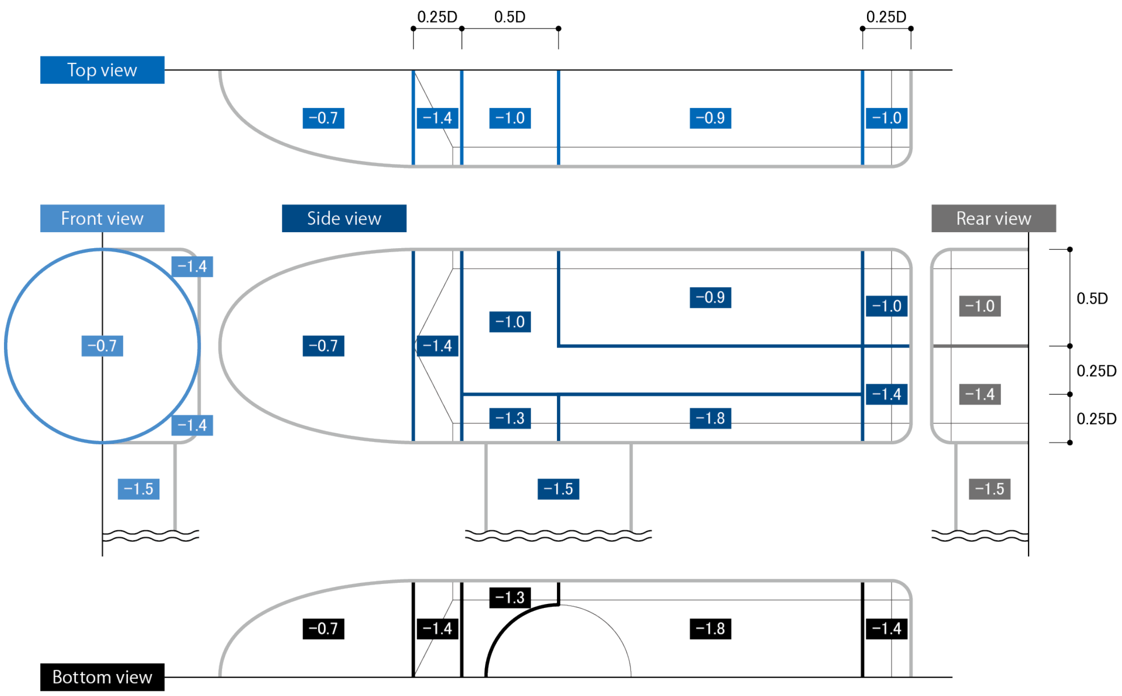

Figure D.3 Equivalent wind pressure coefficient [Wind direction: -15° to +15° - Negative value]

D.3 Equivalent wind pressure coefficient [Wind direction: All wind directions]

-1. The equivalent wind pressure coefficient [positive value] and the equivalent wind pressure coefficient [negative value] obtained from the wind tunnel test results for all wind directions, which are the wind directions to be considered in DLC6.2, are shown in Figure D.4 and D.5, respectively.

-2. The equivalent wind pressure coefficient [positive value] shown in Figure D.4 corresponds to the "$\hat{C}_{em}$ - Positive value" applied to NC.2-1 in Table 5-2, and the equivalent wind pressure coefficient [negative value] shown in Figure D.5 corresponds to the "$\hat{C}_{em}$ - Negative value" applied to NC.2-2 in Table 5-2.

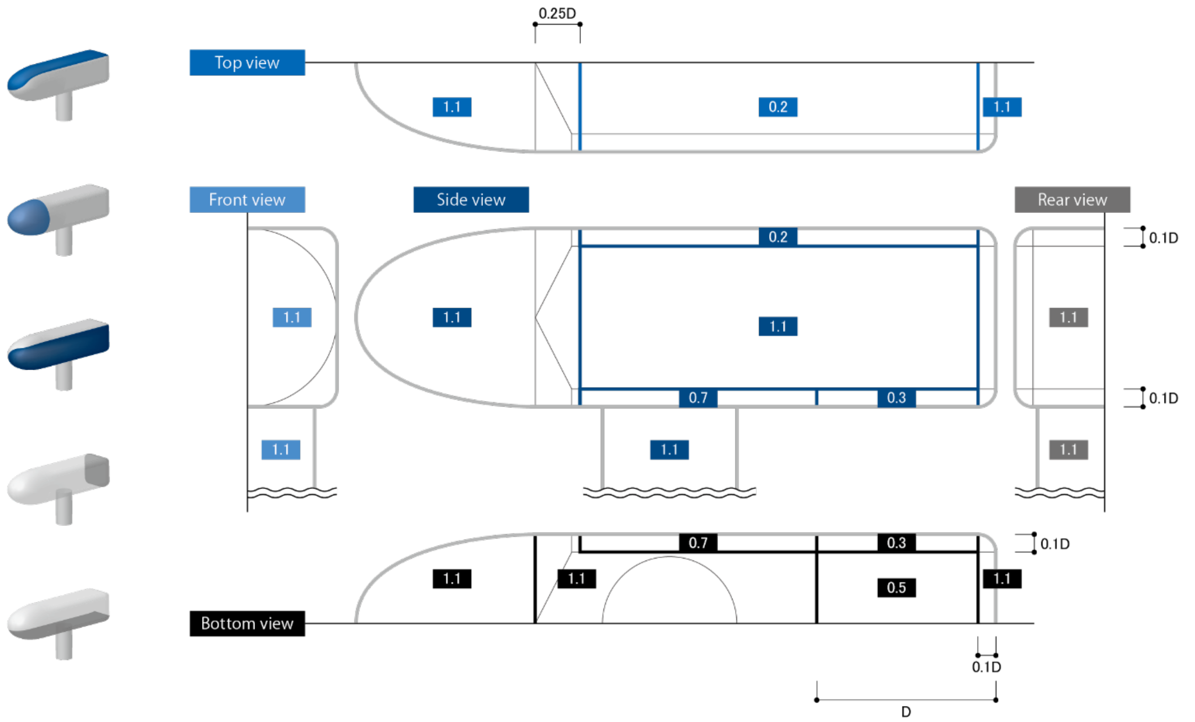

Figure D.4 Equivalent wind pressure coefficient [All wind directions - Positive value]

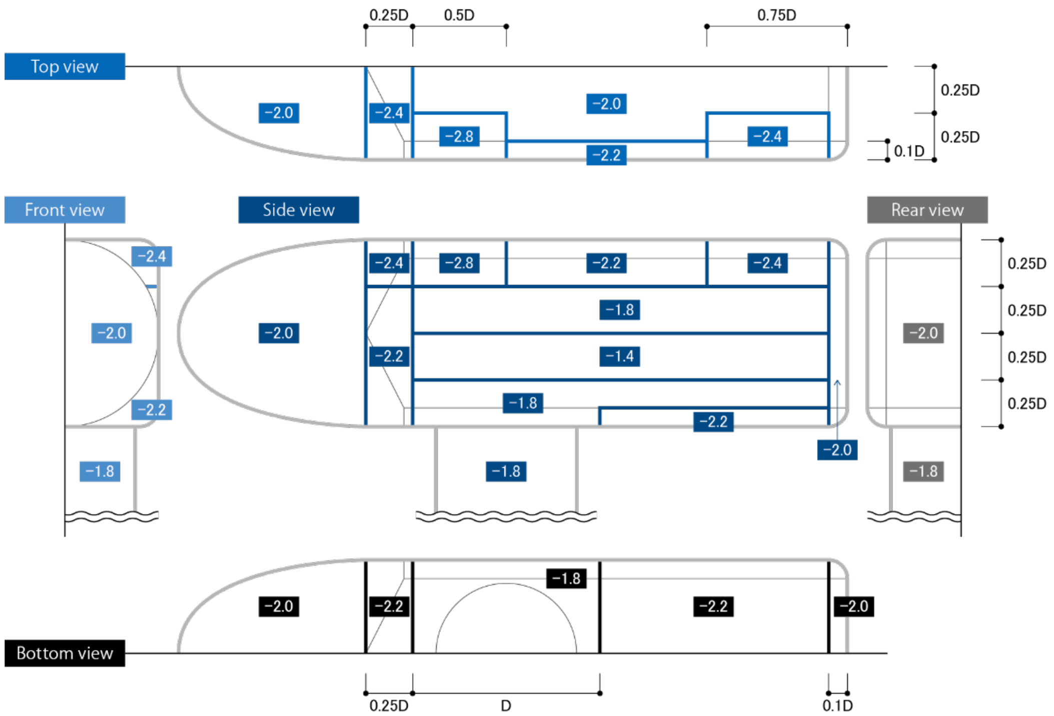

Figure D.5 Equivalent wind pressure coefficient [Wind direction: All wind directions - Negative value]

D.4 Reference documents

[D1] RENEWABLE ENERGY 2019; 2019.10. Nippon Kaiji Kyokai

[D2] H. Noda and T. Ishihara:Wind tunnel test on mean wind forces and peak pressures acting on wind turbine nacelles, Wind Energy 2014; 17:1-17

Annex E. Measurement testing for fluctuating pressure characteristics acting on a nacelle surface [informative]

E.1 General

-1. The values and distributions of the equivalent maximum/minimum wind pressure coefficients for the nacelle cover depend on the shape of the nacelle cover, so it is appropriate to carry out wind tunnel testing according to the wind turbine type in order to conduct the calculations and set the values rationally and on the safe side. This Annex summarizes the contents to be referred to when implementing wind tunnel testing.

-2. Note that the scope of this Annex is wind tunnel tests for the purpose of measuring the fluctuating pressure acting on the surface of the nacelle cover. Wind tunnel tests for the purpose of other measurements are not covered.

E.2 Selection of wind tunnel

-1. A wind tunnel with the performance to meet the following conditions shall be selected.

(1) Wind speed: The air blow capacity must be sufficient for 10 m/s or more in the measurement part

(2) Blockage ratio: The cross-section of the measuring section must have a blockage ratio of 5% or less due to the model

(3) Turbulent boundary layer: It must be possible to simulate and reproduce the various characteristics of natural wind in the wind path (It must be a turbulent boundary layer wind tunnel)

E.3 Model and test conditions

E.3.1 Model

-1. Appropriate scale models that meet the following conditions must be selected and manufactured.

(1) Scale: Must be 1/50 or larger.

- Although a larger scale is desirable, it should be kept in mind that it is necessary to select an appropriate scale model, because there is a limit to the blockage ratio, and also a limit to the generation of a turbulent boundary layer in each individual wind tunnel.
- It should be kept in mind that if the scale is too small, then there may be a problem in the model fabrication accuracy, and that there is a possibility that unreasonableness may occur in the appropriate arrangement and installation of pressure measurement holes.
- Any accessories, etc., may be omitted from the model if the effect is considered to be small for the test purpose.

(2) Pressure measurement hole size: The inside diameter shall be approximately 1 mm.

- The diameter commonly used in building-related pressure measurements is recommended.

(3) Pressure measurement hole arrangement: Holes must be arranged so that the pressure distribution characteristics can be determined within 1 m^2 of the actual machine.

- The fluctuating pressure characteristics on the nacelle shall be measured as accurately as possible, and consideration shall be given so that the wind pressure characteristics can be appropriately evaluated according to the area to be evaluated.
- The minimum size of a panel on the nacelle surface was assumed to be 1 m^2, and this was set as the standard for the pressure hole arrangement.

(4) Materials used and fabrication accuracy: It is recommended to use materials generally used in wind tunnel testing of buildings, and to use the fabrication accuracy applied in relation to buildings.

- It should be noted that a surface roughness problem or corner fabrication accuracy problem may occur with some materials.

E.3.2 Airflow similarity

-1. The wind tunnel tests are conducted by simulating and reproducing the various characteristics of natural wind in the wind path, so the following conditions regarding the various characteristics must be satisfied at the wind speed used in the test implementation.

(1) Wind shear exponent (α)

- The wind shear exponent (α) for the turbulent boundary layer generated shall be in the range of 0.15 to 0.2, corresponding to the ground surface roughness classifications II to III. In consideration of the limit of wind tunnel capacity, the standard for the allowable range of the wind shear exponent (α) shall be 0.125 or more and 0.235 or less.

(2) Turbulence intensity (I_{uH})

- The turbulence intensity (I_{uH}) of the turbulent boundary layer generated must be in the range of 0.13 ± 0.03 at the hub height.

(3) Spectral distribution of turbulence

- The spectrum of turbulence at hub height must be summarized in comparison with the general Karman-type spectrum, and it must be shown that there is no peculiar frequency peak.

(4) Turbulence scale

- The scale of the turbulence in the vicinity of the hub height shall be shown as a reference value.

E.3.3 Wind speed and wind direction in test implementation

-1. The wind tunnel tests are conducted by simulating and reproducing the various characteristics of natural wind in the wind path, so the following conditions regarding the various characteristics must be satisfied at the wind speed used in the test implementation.

(1) Wind speed: The average wind speed at the hub height after the natural wind simulation shall be 8 m/s or more.

- The simulation of the Reynolds number is impossible in general wind tunnels, so for nacelles without sharp edges in particular, there is a possibility that disagreement between the simulation and the actual machines may become a problem. However, it is currently difficult to properly complement (correct) that disagreement, so it shall be acceptable to conduct the testing with the largest Reynolds number that is possible in the wind tunnel concerned.

(2) Wind direction: All wind directions (360°) shall be considered with a pitch of 5°.

- If the shape is symmetrical, the test wind directions may be reduced according to the symmetry.

E.3.4 Pressure measurement instrument

-1. The pressure transducer used shall have a sufficient margin for the magnitude of the fluctuating pressure that occurs and also have no problems regarding its resolution and frequency response characteristics.

-2. For the tube connecting a pressure measurement hole and a pressure transducer, use a tube with an inner diameter and length that takes the frequency response characteristics into consideration. In the pressure measurement, the pressure difference from the static pressure at the reference point is measured, so it must be shown that the reference point is at an appropriate position.

E.3.5 Data processing and recording

-1. As with the selection of pressure measurement equipment, the setting conditions for the wind tunnel test shall be clearly indicated for the following items so that it can be confirmed that the fluctuating pressure characteristics are being correctly recorded and processed. The values in parentheses for each item were the values used in the tests described in Annex D and are provided only as reference values.

(1) Sampling frequency (800 Hz)
(2) Low pass filter (300 Hz)
(3) Time scale (1/10)
(4) Data length per sample (60 seconds)
(5) Number of samples (Ensemble averaging of 5 samples)

-2. The fluctuating pressure depends on the test wind speed and the shape and size of the model, so it should be noted that it is necessary to record and process the fluctuating pressure correctly with consideration of those characteristics.

E.3.6 Maximum/minimum peak wind pressure coefficient

-1. The fluctuating wind pressure measured in the test shall be subjected to the processing shown in E3.5, and the maximum peak wind pressure coefficient $Cp_{\max}$ and minimum peak wind pressure coefficient $Cp_{\min}$ shall be obtained by the dimensionless equations shown in equations (E.1) and (E.2) for each measurement point and each wind direction.

$$Cp_{\max} = (p_e - p_s)_{\max}/q_H \tag{E.1}$$

$$Cp_{\min} = (p_e - p_s)_{\min}/q_H \tag{E.2}$$

Where: p_{e} : Fluctuating wind pressure acting on the model walls (N/m^2)
$(p_{\mathrm{e}} - p_{\mathrm{s}})_{\max}$: Maximum peak wind pressure (N/m^2)
$(p_{\mathrm{e}} - p_{\mathrm{s}})_{\min}$: Minimum peak wind pressure (N/m^2)
p_{s} : Static pressure in the wind tunnel (reference point) (N/m^2)
q_H : Average hub height speed pressure (N/m^2)

-2. Note that the maximum and minimum peak wind pressure coefficients must each be calculated in the form corresponding to the DLC6.1 and DLC6.2 design load cases shown in 5.3.3 (Specifically, with the range of wind direction limited).

E.4 Reference documents

[E1] H. Noda and T. Ishihara:Wind tunnel test on mean wind forces and peak pressures acting on wind turbine nacelles, Wind Energy 2014; 17:1-17
[E2] RENEWABLE ENERGY 2019; 2019.10. Nippon Kaiji Kyokai
[E3] Noda Hiroshi and Ishihara Tsutomu: Wind Tunnel Tests for Mean Wind Forces and Peak Pressures Acting on Wind Turbine Nacelles, JAWE, Vol. 35, No. 1, 2010.1.
[E4] Guidelines for Design of Wind Turbine Support Structures and Foundation [2010 version] (Japan Society of Civil Engineers)
[E5] Architectural Institute of Japan: Recommendations for Loads on Buildings (2015), February 25, 2015 5th Edition, 1st printing, Maruzen Publishing Co., Ltd.
[E6] Japan Society of Civil Engineers: Structural Engineering Series 12 - Wind resistant design of bridges - Criteria and recent advances -, March 31, 2003 1st edition, 1st printing, Maruzen Publishing Co., Ltd.
[E7] Japan Road Association: Road Bridge Wind Resistant Design Handbook (Revised 2007), January 25, 2008 revised edition 1st printing, Maruzen Publishing Co., Ltd.
[E8] The Building Center of Japan: Guidebook on architecture wind tunnel experiments for practitioners, 2008
[E9] Masakuni Yoshida et al.: Transfer function of a single PCB tube and the digital correction of fluctuating wind pressure, Proceedings of 9th National Symposium on Wind Engineering, 1986
[E10] ClassNK Renewable Energy:Japanese requirements for Globe type nacelle cover

Annex F. Design methodologies for tower structures [normative]

F.1 General

-1. This Annex summarizes the methods that meet the requirements for general facility, in 2. (3) [2] specified in the Implementation procedures for the examination of construction plans for the installation or modification of wind power plants[R-03].

F.2 Attenuation

-1. For the first and second mode structural damping ratios for cylindrical steel structures, the values obtained from equation (F.1) and equation (F.2) [R-09] [R-12] [F1] may be applied. When using values other than this, it is necessary to explain the validity of the values. In addition, for the modal damping ratio that consists of the structural damping and ground damping, evaluation is possible in the method shown in the reference document[F2]. Furthermore, in the time history response analysis using the SR model, the soil damping is considered as a dashpot[F2].

$$\zeta_{struc_1}(\%) = \max(2.0e^{-1.3T_1} + 0.15, 0.2) \tag{F.1}$$

$$\zeta_{struc_2}(\%) = \zeta_{struc_1}(\%) \tag{F.2}$$

F.3 Anchor bolt hole diameter

-1. When the hole diameter of the anchor bolt exceeds the nominal diameter of the bolt + 5 mm, the following both [1] and [2] shall be satisfied.

[1] The hole diameter of anchor bolts shall not exceed the clearance based on the nominal bolt diameter specified in ISO273[R-11].

[2] Following the Guidebook on Design and Fabrication of High Strength Bolted Connections[R-05], if the nominal bolt diameter exceeds 24 mm, the hole diameter may be the bolt diameter + 8 mm on the premise that the slip resistance is reduced (reduction factor: 0.85). Therefore, in the most severer loading conditions based on the site conditions, the horizontal force due to the shear force and torsional moment acting on the tower base, and the frictional force (resistance friction force) on the underside of the base plate should be compared considering the reduction factor of 0.85, and it must be confirmed that the "Resistance friction force considering horizontal force/reduction factor" is less than 1.0.

F.4 Design applying the fatigue equivalent design method in structural calculations for anchor bolts

-1. For the design bolt tension and short-term allowable tensile force for anchor bolts, the approach of the "fatigue strength design method" shown in (1) may be applied. However, in this case, it is necessary to satisfy the requirements concerning fatigue strength evaluation shown in (2).

(1) There are regulations for tower flange bolts in item 7.3.2 of the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and the short term allowable tensile force and design bolt tension when adopting the fatigue strength design method for high strength bolts for flange joints are regulated as equation (7.2) and equation (7.3) shown below. In addition, the allowable tensile force in extremely rare earthquakes in this case is determined as equation (7.a).

When fatigue evaluations that include strong winds up to the design wind speed have been carried out and it has been confirmed that bolt fatigue damage will not occur during the service period, the short-term allowable tensile force is the value obtained by multiplying the effective cross-sectional area of the bolt thread part by 0.8 times the yield strength and is determined by equation (7.2).

$$T_a = 0.80 \cdot \sigma_y \cdot A_e \tag{7.2}$$

However, the design bolt tension is the value obtained by multiplying the effective cross-sectional area of the bolt thread part by 0.7 times the yield strength and is determined by equation (7.3).

$$N_0 = 0.70 \cdot \sigma_y \cdot A_e \tag{7.3}$$

The force acting in the axial direction T caused by the external force per anchor bolt in extremely rare earthquakes must not exceed the allowable tensile force T_{ar} in extremely rare earthquakes.

$$T_{ar} = \max\left(0.80 \cdot \sigma_y \cdot A_e,\ A_e \cdot F_{by}\right) \tag{7.a}$$

Where:

σ_y : Anchor bolt yield strength [N/mm^2]

A_e : Effective cross-sectional area of anchor bolt [mm^2]

F_{by} : Determined by the smaller of the anchor bolt reference strength [N/mm^2], yield strength, and 70% of the tensile strength.

(2) When the design bolt axial force for an anchor bolt is set by adopting the fatigue strength design method shown in (1) above, the requirements related to fatigue strength evaluation are as shown below.

1) Principle for conducting fatigue strength evaluation

- This shall follow item 7.4.1 in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and the degree of fatigue damage shall be determined by the cumulative fatigue damage rule.

2) The requirements for each item to be considered shall be as shown in Table F.1.

Table F.1 Items to be considered for fatigue strength evaluation and their requirements

Items to be considered	Applicable specifications and standards	Requirements
Anchor bolts	EN 1993-1-9: 2005[R-13]	・ When considering only the axial force on the anchor bolt and not bending, apply *DC36** as the S-N diagram. *1 ・ The size effect reduction factor: *ks* shall be considered.
Grout / Concrete	MC2010[R-14] (MC1990[R-15] is also possible)	・ In principle, consideration of the three-dimensional restraint effect is not accepted. *2 ・ The concrete strength applied to the fatigue strength consideration shall be the concrete strength adopted at the site. Also, the basic rule is the application of 28-day strength.

*1: See the column of requirements for *DC50* on Table 8.1 of EN 1993-1-9: 2005[R-07]
(In addition, refer to the Guidance note in item 4.12.3.6 of DNVGL-ST-0126[R-12].)

*2: When adopting fatigue design strength that considers the three-dimensional restraint effect, its validity must be shown by quantitative verification results based on fatigue experiment results, etc.

F.5 Lever ratio of flange joint

-1. Regarding the tensile strength of a flange joint bolt, if the lever ratio (e/g) exceeds 1.25, checking can be carried out based on the proposed equation in the reference document[F3] within the application range shown in this reference.

F.6 Design applying the fatigue equivalent design method in structural calculations for flange joints

-1. For the short-term allowable tensile force and design bolt tension for flange joints, the approach of the "fatigue strength design method" shown in (1) may be applied. However, in this case, it is necessary to satisfy the requirements concerning fatigue strength evaluation shown in (2).

(1) There are regulations for tower flange bolts in item 7.3.2 of the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and the short term allowable tensile force and design bolt tension when adopting the fatigue strength design method for high strength bolts for flange joints are regulated as equation (7.2) and equation (7.3) shown in F.4.

(2) When the design bolt axial force for a flange bolt is set by adopting the fatigue strength design method shown in (1) above, the requirements related to fatigue strength evaluation are as shown below.

1) Principle for conducting fatigue strength evaluation

- This shall follow item 7.4.1 in the Guidelines for Design of Wind Turbine Support Structures and Foundation[J-05], and the degree of fatigue damage shall be determined by the cumulative fatigue damage rule.

2) The requirements for each item to be considered shall be as shown in Table F.2.

Table F.2 Items to be considered for fatigue strength evaluation and their requirements

Items to be considered	Applicable specifications and standards	Requirements
Flange bolt	EN 1993-1-9: 2005[R-13]	・ When considering only the axial force on the anchor bolt and not bending, apply *DC36** as the S-N diagram. *1 ・ The size effect reduction factor: *ks* shall be considered.

*1: See the column of requirements for *DC50* on Table 8.1 of EN 1993-1-9: 2005[R-07]
(In addition, refer to the Guidance note in item 4.12.3.6 of DNVGL-ST-0126[R-12].)

F.7 Reference documents

[F1] S. Oh, T. Ishihara, Structural parameter identification of a 2.4MW bottom fixed wind turbine by excitation test using an active mass damper, Wind Energy, 21(11):1232-1238, 2018.

[F2] T. Ishihara, L. Wang, A study of modal damping for offshore wind turbines considering soil properties and foundation types, Wind Energy, 22(12):1760-1778, 2019.

[F3] Ikuo Tobinaga, Takeshi Ishihara: A study of action point correction factor for L-type flange of wind turbine towers, Japan Wind Energy Association proceedings, Vol. 40, No. 2, August 2016

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