



**SLOVENSKI STANDARD  
SIST EN IEC 61400-6:2020**

**01-september-2020**

---

**Sistemi za proizvodnjo energije na veter - 6. del: Stolp in obravnava temeljnih zahtev (IEC 61400-6:2020)**

Wind energy generation systems - Part 6: Tower and foundation design requirements (IEC 61400-6:2020)

Windenergieanlagen - Teil 6: Auslegungsanforderungen an Türme und Fundamente (IEC 61400-6:2020)

Systèmes de génération d'énergie éolienne – Partie 6: Exigences en matière de conception du mât et de la fondation (IEC 61400-6:2020)

<https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0a0b569bb/sist-en-iec-61400-6:2020>

**Ta slovenski standard je istoveten z: EN IEC 61400-6:2020**

---

**ICS:**

27.180      Vetrne elektrarne      Wind turbine energy systems

**SIST EN IEC 61400-6:2020      en**

**iTeh STANDARD PREVIEW**  
**(standards.iteh.ai)**

SIST EN IEC 61400-6:2020

<https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0ca0eb569bb/sist-en-iec-61400-6-2020>

EUROPEAN STANDARD

EN IEC 61400-6

NORME EUROPÉENNE

EUROPÄISCHE NORM

June 2020

ICS 27.180

English Version

## Wind energy generation systems - Part 6: Tower and foundation design requirements (IEC 61400-6:2020)

Systèmes de génération d'énergie éolienne - Partie 6 :  
Exigences en matière de conception du mât et de la  
fondation  
(IEC 61400-6:2020)

Windenergieanlagen - Teil 6: Auslegungsanforderungen an  
Türme und Fundamente  
(IEC 61400-6:2020)

This European Standard was approved by CENELEC on 2020-05-26. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

SIST EN IEC 61400-6:2020

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



European Committee for Electrotechnical Standardization  
Comité Européen de Normalisation Electrotechnique  
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

**EN IEC 61400-6:2020 (E)****European foreword**

The text of document 88/751/FDIS, future edition 1 of IEC 61400-6, prepared by IEC/TC 88 "Wind energy generation systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 61400-6:2020.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2021-02-26
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2023-05-26

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

**iTeh STANDARD PREVIEW**  
**Endorsement notice**  
**(standards.iteh.ai)**

The text of the International Standard IEC 61400-6:2020 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

ISO 148-1	NOTE	Harmonized as EN ISO 148-1
ISO 9001	NOTE	Harmonized as EN ISO 9001
ISO/IEC 17025	NOTE	Harmonized as EN ISO/IEC 17025

## Annex ZA (normative)

### Normative references to international publications with their corresponding European publications

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: [www.cenelec.eu](http://www.cenelec.eu).

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 61400-1	2019	Wind energy generation systems - Part 1: Design requirements	EN IEC 61400-1	2019
IEC 61400-2	-	Wind turbines - Part 2: Small wind turbines	EN 61400-2	-
IEC 61400-3-1	2019	Wind energy generation systems - Part 3-1: Design requirements for fixed offshore wind turbines	EN IEC 61400-3-1	2019
ISO 2394	2015	General principles on reliability for structures	-	-
ISO 22965-1	-	Concrete - Part 1: Methods of specifying and guidance for the specifier	-	-
ISO 22965-2	-	Concrete - Part 2: Specification of constituent materials, production of concrete and compliance of concrete	-	-
ISO 22966	-	Execution of concrete structures	-	-
ISO 6934	series	Steel for the prestressing of concrete	-	-
ISO 6935	series	Steel for the reinforcement of concrete	-	-
ISO 9016	2012	Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination	EN ISO 9016	2012
ISO 12944	series	Paints and varnishes - Corrosion protection of steel structures by protective paint systems	-	-
EN 1993-1-9	2005	Eurocode 3: Design of steel structures - Part 1-9: Fatigue	-	-
EN 1993-3-2	2006	Eurocode 3: Design of steel structures - Part 3-2: Towers, masts and chimneys - Chimneys	-	-

**iTeh STANDARD PREVIEW**  
**(standards.iteh.ai)**

SIST EN IEC 61400-6:2020

<https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0ca0eb569bb/sist-en-iec-61400-6-2020>



IEC 61400-6

Edition 1.0 2020-04

# INTERNATIONAL STANDARD



---

**Wind energy generation systems –  
Part 6: Tower and foundation design requirements**

**STANDARD PREVIEW**  
(standards.iteh.ai)

SIST EN IEC 61400-6:2020  
<https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0ca0eb569bb/sist-en-iec-61400-6-2020>

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 27.180

ISBN 978-2-8322-8004-1

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	9
INTRODUCTION.....	11
1 Scope.....	12
2 Normative references .....	12
3 Terms and definitions .....	13
4 Symbols and abbreviated terms.....	17
4.1 Symbols.....	17
4.2 Abbreviated terms.....	19
5 Design basis including loading.....	20
5.1 General.....	20
5.2 Basis of design .....	20
5.2.1 Basic principles .....	20
5.2.2 Durability .....	21
5.2.3 Principles of limit state design .....	21
5.2.4 Structural analysis .....	21
5.2.5 Assessments by tests .....	22
5.3 Materials.....	22
5.4 Loads.....	22
5.4.1 Use of IEC 61400-1 or IEC 61400-2 load cases and partial safety factors for loads.....	22
5.4.2 Superseding of IEC 61400-1 or IEC 61400-2 partial safety factors for materials .....	22
5.4.3 Serviceability load levels.....	23
5.4.4 Load combinations in ULS.....	24
5.4.5 Structural damping values to be used in load calculations .....	25
5.4.6 Definitions and methods for use of internal loads.....	25
5.4.7 Definition of required load data for fatigue analysis.....	25
5.4.8 Definition of required load data for extreme load level .....	25
5.4.9 Vortex induced vibration .....	26
5.4.10 Loads due to geometric tolerances and elastic deflections in tower verticality.....	26
5.5 Load data and interface reporting requirements .....	27
5.5.1 Purpose.....	27
5.5.2 Wind turbine specification.....	27
5.5.3 Time history data.....	28
5.5.4 Load origins.....	28
5.5.5 Load components .....	28
5.6 General structural design requirements.....	28
5.6.1 Secondary structural influence.....	28
5.6.2 Fatigue analysis .....	28
5.7 Delivery documentation.....	28
6 Steel towers .....	29
6.1 General.....	29
6.2 Basis of design .....	29
6.3 Materials.....	29
6.3.1 General .....	29
6.3.2 Structural steels .....	29



6.3.3	Bolts and anchors .....	32
6.4	Ultimate strength analysis for towers and openings .....	32
6.4.1	General .....	32
6.4.2	Partial safety factors .....	32
6.4.3	Verification of ultimate strength .....	32
6.4.4	Tower assessment .....	32
6.4.5	Detail assessments .....	33
6.5	Stability .....	33
6.5.1	General .....	33
6.5.2	Partial safety factor .....	34
6.5.3	Assessment .....	34
6.5.4	Door frames/stiffeners .....	34
6.6	Fatigue limit state .....	35
6.6.1	General .....	35
6.6.2	Partial safety factor for materials .....	35
6.6.3	Assessment .....	36
6.6.4	Details .....	36
6.7	Ring flange connections .....	36
6.7.1	General .....	36
6.7.2	Design assumptions and requirements, execution of ring flanges .....	36
6.7.3	Ultimate limit state analysis of flange and bolted connection .....	38
6.7.4	Fatigue limit state analysis of bolted connection .....	38
6.8	Bolted connections resisting shear through friction .....	40
6.8.1	General requirements .....	40
6.8.2	Test-assisted design .....	41
6.8.3	Design without test .....	42
7	Concrete towers and foundations .....	42
7.1	General .....	42
7.2	Basis of design .....	42
7.2.1	Reference standard for concrete design .....	42
7.2.2	Partial safety factors .....	43
7.2.3	Basic variables .....	43
7.3	Materials .....	45
7.4	Durability .....	46
7.4.1	Durability requirements .....	46
7.4.2	Exposure classes .....	46
7.4.3	Concrete cover .....	46
7.5	Structural analysis .....	46
7.5.1	Finite element analysis .....	46
7.5.2	Foundation slabs .....	47
7.5.3	Regions with discontinuity in geometry or loads .....	47
7.5.4	Cast in anchor bolt arrangements .....	48
7.6	Concrete to concrete joints .....	48
7.7	Ultimate limit state .....	48
7.7.1	General .....	48
7.7.2	Shear and punching shear .....	48
7.8	Fatigue limit state .....	49
7.8.1	General .....	49
7.8.2	Reinforcement and prestressing steel fatigue failure .....	49

7.8.3	Concrete fatigue failure .....	49
7.9	Serviceability limit state .....	50
7.9.1	Load dependent stiffness reduction .....	50
7.9.2	Stress limitation .....	50
7.9.3	Crack control .....	50
7.9.4	Deformations .....	51
7.10	Execution .....	51
7.10.1	General .....	51
7.10.2	Requirements .....	51
7.10.3	Inspection of materials and products .....	51
7.10.4	Falsework and formwork .....	51
7.10.5	Reinforcement and embedded steel .....	51
7.10.6	Pre-stressing .....	51
7.10.7	Precast concrete elements .....	52
7.10.8	Geometrical tolerances .....	52
8	Foundations – Geotechnical design .....	52
8.1	General .....	52
8.2	Basis of design .....	52
8.2.1	General .....	52
8.2.2	Geotechnical limit states .....	53
8.3	Geotechnical data .....	53
8.3.1	General .....	53
8.3.2	Specific considerations .....	55
8.4	Supervision, monitoring and maintenance of construction .....	56
8.5	Gravity base foundations .....	56
8.5.1	General .....	56
8.5.2	Ultimate limit state (ULS) .....	57
8.5.3	Serviceability limit state (SLS) .....	60
8.6	Piled foundations .....	62
8.6.1	General .....	62
8.6.2	Pile loads .....	62
8.6.3	Ultimate limit state .....	63
8.6.4	Serviceability limit state .....	64
8.7	Rock anchored foundations .....	65
8.7.1	General .....	65
8.7.2	Types of rock anchor foundation .....	65
8.7.3	Geotechnical data .....	65
8.7.4	Corrosion protection .....	65
8.7.5	Anchor inspection and maintenance .....	66
8.7.6	Post tension tolerances and losses .....	66
8.7.7	Ultimate limit state .....	66
8.7.8	Serviceability limit state .....	67
8.7.9	Robustness check .....	67
8.7.10	Rock anchor design .....	68
9	Operation, service and maintenance requirements .....	70
9.1	Operation, maintenance and monitoring .....	70
9.2	Periodic structural inspections .....	70
9.3	Embedded steel structural section inspections .....	71
9.4	Bolt tension maintenance .....	71

9.5	Structural health monitoring .....	71
Annex A (informative)	List of suitable design codes and guidelines for the calculation basis .....	72
A.1	General.....	72
A.2	Reference documents .....	72
Annex B (informative)	List of material for structural steel .....	73
B.1	General.....	73
B.2	Structural steel .....	73
Annex C (informative)	Bolts .....	74
C.1	General.....	74
C.2	Reference documents .....	75
Annex D (informative)	Z-values for structural steel.....	76
D.1	General.....	76
D.2	Definition of Z-value according to Eurocode .....	76
D.3	Reference documents .....	76
Annex E (informative)	Simplified buckling verification for openings in tubular steel towers.....	77
Annex F (informative)	Fatigue verification .....	80
F.1	General.....	80
F.2	Specific details .....	80
Annex G (informative)	Methods for ring flange verification .....	81
G.1	Method for ultimate strength analysis according to Petersen/Seidel .....	81
G.1.1	Basics .....	81
G.1.2	Calculation method .....	81
G.1.3	Extension by Tobinaga and Ishihara .....	84
G.2	Method for fatigue strength analysis according to Schmidt/Neuper.....	85
G.2.1	Basics .....	85
G.2.2	Formulas for the tri-linear approximation.....	86
G.3	Reference documents .....	87
Annex H (informative)	Crack control – Guidance on 7.9.3 .....	88
H.1	General.....	88
H.2	Crack control based on Eurocode 2 .....	88
H.3	Crack control based on Japanese standards.....	88
H.4	Crack control based on ACI 318.....	89
H.5	Reference documents .....	89
Annex I (informative)	Finite element analysis for concrete.....	90
I.1	General.....	90
I.2	Order and type of elements.....	90
I.3	Constitutive modelling.....	91
I.4	Solution methods .....	91
I.5	Implicit approach .....	91
I.6	Steps in conducting of a finite element analysis .....	92
I.7	Checking results .....	92
I.8	Reference documents .....	93
Annex J (informative)	Tower-foundation anchorage .....	94
J.1	General.....	94
J.2	Embedded anchorages .....	94
J.3	Bolted anchorages .....	95

J.4	Grout .....	95
J.5	Anchor bolts.....	95
J.6	Embedded ring .....	95
J.7	Anchorage load transfer.....	96
Annex K	(informative) Strut-and-tie section .....	97
K.1	General.....	97
K.2	Example of a rock anchor foundation .....	98
K.3	Reference documents .....	101
Annex L	(informative) Guidance on selection of soil modulus and foundation rotational stiffness .....	103
L.1	General.....	103
L.2	Soil model.....	103
L.3	Dynamic rotational stiffness .....	105
L.4	Static rotational stiffness .....	106
L.5	Reference documents .....	107
Annex M	(informative) Guidance for rock anchored foundation design .....	108
M.1	General.....	108
M.2	Corrosion protection .....	108
M.2.1	Standard anchors .....	108
M.2.2	Corrosion protection of bar anchors.....	109
M.3	Product approval.....	110
M.4	Rock anchor design .....	110
M.5	Grout design .....	110
M.6	Testing and execution.....	110
M.7	Suitability/performance test.....	111
M.8	Acceptance/proof test.....	111
M.9	Supplementary extended creep tests .....	111
M.10	Reference documents .....	111
Annex N	(informative) Internal loads – Explanation of internal loads .....	112
Annex O	(informative) Seismic load estimation for wind turbine tower and foundation.....	114
O.1	General.....	114
O.2	Vertical ground motion .....	114
O.3	Structure model .....	114
O.4	Soil amplification.....	115
O.5	Time domain simulation .....	116
O.6	Reference documents .....	116
Annex P	(informative) Structural damping ratio for the tower of wind turbine .....	117
P.1	General.....	117
P.2	First mode structural damping ratio.....	117
P.3	Second mode structural damping ratio .....	118
P.4	Higher mode damping .....	118
P.5	Reference documents .....	119
Annex Q	(informative) Guidance on partial safety factors for geotechnical limit states .....	120
Q.1	General.....	120
Q.2	Equilibrium.....	120
Q.3	Bearing capacity .....	120
Q.4	Sliding resistance .....	121
Q.5	Overall stability .....	121

Q.6 Reference documents .....	122
Bibliography.....	123
Figure 1 – Flange notations as an example of an L-flange .....	31
Figure 2 – Door opening geometry .....	35
Figure 3 – Flange gaps $k$ in the area of the tower wall .....	37
Figure 4 – Bolt force as a function of wall force.....	39
Figure 5 – S-N curve for detail category 36 .....	40
Figure 6 – Thermal effects around tower cross-section .....	44
Figure 7 – Illustration of rock anchor length .....	70
Figure E.1 – Circumferentially edge-stiffened opening .....	78
Figure E.2 – Definition of $W_s$ and $t_s$ according to JSCE .....	79
Figure G.1 – Simplification of system to segment model .....	81
Figure G.2 – Locations of plastic hinges for different failure modes.....	82
Figure G.3 – Geometric parameters .....	83
Figure G.4 – Modification factor $\lambda$ for different $\alpha$ [1] .....	85
Figure G.5 – Tri-linear approximation of the non-linear relation between bolt force and tension force of the bolted connection.....	86
Figure K.1 – Example for the design of a deep beam using the strut-and-tie method.....	97
Figure K.2 – Simple shapes of strut-and-tie models.....	97
Figure K.3 – Three examples for carrying load in a deep beam .....	98
Figure K.4 – Strut-and-tie models for a rock-anchor foundation.....	101
Figure K.5 – Top tie reinforcement in a rock-anchor foundation.....	101
Figure L.1 – Example stress-strain relationship for soil .....	103
Figure L.2 – Loading and unloading behaviour of soil .....	104
Figure L.3 – Variation of shear modulus with soil strain.....	105
Figure L.4 – Reduction in rotational stiffness due to load eccentricity.....	106
Figure L.5 – Illustrative example of reduction in foundation rotational stiffness due to increasing load eccentricity.....	107
Figure M.1 – Section through rock and anchor.....	108
Figure M.2 – Typical anchor configuration with corrosion protection.....	109
Figure N.1 – Representation of internal loads .....	113
Figure O.1 – Structure model for response spectrum method.....	115
Figure P.1 – First mode damping ratio for the steel tower of wind turbine.....	118
Table 1 – Flange tolerances.....	37
Table 2 – Summary of geotechnical limit states .....	53
Table B.1 – National and regional steel standards and types .....	73
Table C.1 – Comparison of bolt material in ISO 898-1, JIS B1186 and ASTM A490M-12.....	74
Table E.1 – Coefficients for Formula (E.3) .....	78
Table H.1 – Limit value of crack width based on Japanese standards [1] .....	89
Table P.1 – Damping coefficients.....	117
Table Q.1 – Minimum partial safety factors for the equilibrium limit state (European and North American practice).....	120

Table Q.2 – Minimum partial safety factors on for the equilibrium limit state (JSCE) .....	120
Table Q.3 – Minimum partial material and resistance factors for the bearing resistance limit state, ULS .....	121
Table Q.4 – Minimum partial material and resistance factors for the sliding resistance limit state, ULS .....	121
Table Q.5 – Minimum partial material and resistance factors for the overall stability limit state, ULS .....	122

## **iTeh STANDARD PREVIEW** **(standards.iteh.ai)**

[SIST EN IEC 61400-6:2020](https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0ca0eb569bb/sist-en-iec-61400-6-2020)

<https://standards.iteh.ai/catalog/standards/sist/c8800e65-d07a-4573-b208-c0ca0eb569bb/sist-en-iec-61400-6-2020>

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## WIND ENERGY GENERATION SYSTEMS –

## Part 6: Tower and foundation design requirements

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61400-6 has been prepared by IEC technical committee TC 88: Wind energy generation systems.

The text of this standard is based on the following documents:

FDIS	Report on voting
88/751/FDIS	88/754/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.