SLOVENSKI STANDARD
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Evrokod 9 - Projektiranje konstrukcij iz aluminijevih zlitin - 1-5. del: Lupinaste konstrukcije

Eurocode 9 - Design of aluminium structures - Part 1-5: Shell structures

Eurocode 9 - Bemessung und Konstruktion von Aluminiumtragwerken - Teil 1-5: Schalentragwerke

Eurocode 9 - Calcul des structures en aluminium - Partie 1-5 : Coques

Ta slovenski standard je istoveten z: **EN 1999-1-5:2023**

ICS:

91.010.30	Tehnični vidiki	Technical aspects
91.080.17	Aluminijaste konstrukcije	Aluminium structures

SIST EN 1999-1-5:2023 **en,fr,de**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1999-1-5

March 2023

ICS 91.010.30; 91.080.17

Supersedes EN 1999-1-5:2007

English Version

Eurocode 9 - Design of aluminium structures - Part 1-5: Shell structures

Eurocode 9 - Calcul des structures en aluminium - Partie 1-5 : Coques

Eurocode 9 - Bemessung und Konstruktion von Aluminiumtragwerken - Teil 1-5: Schalentragwerke

This European Standard was approved by CEN on 2 January 2023.

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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 CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (EN 1999-1-5:2023) has been prepared by Technical Committee CEN/TC250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2027, and conflicting national standards shall be withdrawn at the latest by March 2028.

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

This document supersedes EN 1999-1-5:2007.

The main changes compared to the previous edition are listed below:

— Some reorganization of the text and its coherence with EN 1999-1-1 and the other Eurocodes;

— Update of Annex A on buckling formulae for cylinders, cones and spheres;

— New, more accurate formulation for imperfection reduction factors given in Annex A, related to unstiffened and stiffened shells under axial load, circumferential pressure and shear, including the case of axial compression with coexistent internal pressure;

— Better fitting of buckling curves against benchmarked available data, also considering the addition of a new material class in EN 1999, which led to three buckling classes A, B and C;

— Improvement of wording.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

— EN 1990 Eurocode: Basis of structural and geotechnical design

— EN 1991 Eurocode 1: Actions on structures

— EN 1992 Eurocode 2: Design of concrete structures

— EN 1993 Eurocode 3: Design of steel structures

— EN 1994 Eurocode 4: Design of composite steel and concrete structures

— EN 1995 Eurocode 5: Design of timber structures

— EN 1996 Eurocode 6: Design of masonry structures

— EN 1997 Eurocode 7: Geotechnical design

— EN 1998 Eurocode 8: Design of structures for earthquake resistance

— EN 1999 Eurocode 9: Design of aluminium structures

— New parts are under development, e.g. Eurocode for design of structural glass

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1999 (all parts)

EN 1999 (all parts) applies to the design of buildings and civil engineering and structural works made of aluminium. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990.

EN 1999 (all parts) is only concerned with requirements for resistance, serviceability, durability and fire resistance of aluminium structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered.

EN 1999 (all parts) does not cover the special requirements of seismic design. Provisions related to such requirements are given in EN 1998, which complements, and is consistent with EN 1999.

Eurocode 9 is subdivided in various parts:

— EN 1999-1-1 Eurocode 9 — Design of Aluminium Structures — Part 1-1: General rules;

— EN 1999-1-2 Eurocode 9 — Design of Aluminium Structures — Part 1-2: Structural fire design;

— EN 1999-1-3 Eurocode 9 — Design of Aluminium Structures — Part 1-3: Structures susceptible to fatigue;

— EN 1999-1-4 Eurocode 9 — Design of Aluminium Structures — Part 1-4: Cold-formed structural sheeting;

— EN 1999-1-5 Eurocode 9 — Design of Aluminium Structures — Part 1-5: Shell structures.

0.3 Introduction to EN 1999-1-5

This document applies to the structural design of aluminium structures, stiffened and unstiffened, that have the form of a shell of revolution or of a round panel in monocoque structures.

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National annex for EN 1999-1-5

National choice is allowed in this standard where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing EN 1999-1-5 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this standard is to be used.

When no national choice is made and no default is given in this standard, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

National choice is allowed in EN 1999-1-5 through the following clauses:

— N/A

National choice is allowed in EN 1999-1-5 on the application of the following informative annexes:

Annex B

1 Scope

1.1 Scope of EN 1999-1-5

(1) EN 1999-1-5 applies to the structural design of aluminium structures, stiffened and unstiffened, that have the form of a shell of revolution or of a round panel in monocoque structures.

(2) EN 1999-1-5 covers additional provisions to those given in the relevant parts of EN 1999 for design of aluminium structures.

NOTE Supplementary information for certain types of shells is given in EN 1993-1-6 and the relevant application parts of EN 1993 which include:

— Part 3-1 for towers and masts;

— Part 3-2 for chimneys;

— Part 4-1 for silos;

— Part 4-2 for tanks;

— Part 4-3 for pipelines.

(4) The provisions in EN 1999-1-5 apply to axisymmetric shells (cylinders, cones, spheres) and associated circular or annular plates, beam section rings and stringer stiffeners, where they form part of the complete structure.

(5) Single shell panels (cylindrical, conical or spherical) are not explicitly covered by EN 1999-1-5. However, the provisions can be applicable if the appropriate boundary conditions are duly taken into account.

(6) Types of shell walls covered in EN 1999-1-5 can be (see Figure 1.1):

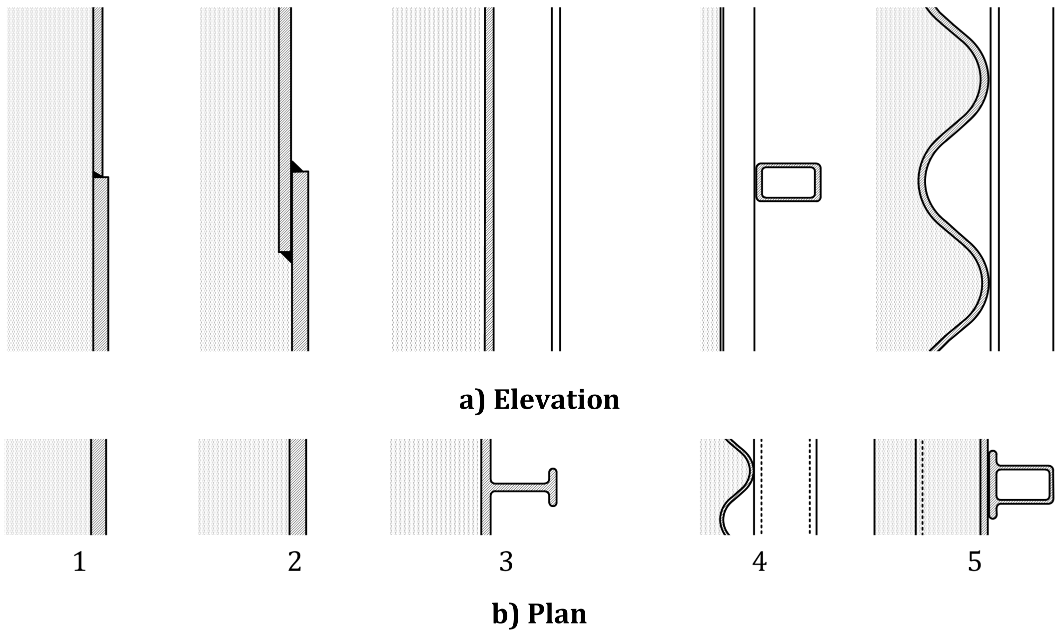
— shell wall constructed from flat rolled sheet with adjacent plates connected with butt welds, termed “isotropic”;

— shell wall with lap joints formed by connecting adjacent plates with overlapping sections, termed “lap-jointed”;

— shell wall with stiffeners attached to the outside, termed “externally stiffened” irrespective of the spacing of stiffeners;

— shell wall with the corrugations running up the meridian, termed “axially corrugated”;

— shell wall constructed from corrugated sheets with the corrugations running around the shell circumference, termed “circumferentially corrugated”.



Key

1 Isotropic (unstiffened)

2 Lap-joined

3 Externally stiffened

4 Axially corrugated

5 Circumferentially corrugated

Figure 1.1 — Illustration of cylindrical shell form

(7) The provisions of EN 1999-1-5 are intended to be applied within the temperature range defined in EN 1999-1-1. The maximum temperature is restricted so that the influence of creep can be neglected. For structures subject to elevated temperatures associated with fire, see EN 1999-1-2.

(8) EN 1999-1-5 does not cover the aspect of leakage.

1.2 Assumptions

(1) The general assumptions of EN 1990 apply.

(2) The provisions of EN 1999-1-1 apply.

(3) The design procedures are valid only when the requirements for execution in EN 1090-3 or other equivalent requirements are complied with.

(4) For the design of new structures, EN 1999 is intended to be used, for direct application, together with EN 1990, EN 1991, EN 1992, EN 1993, EN 1994, EN 1995, EN 1997 and EN 1998.

(5) EN 1999 is intended to be used in conjunction with:

— European Standards for construction products relevant for aluminium structures;

— EN 1090-1, *Execution of steel structures and aluminium structures — Part 1: Requirements for conformity assessment of structural components*;

— EN 1090-3, *Execution of steel structures and aluminium structures — Part 3: Technical requirements for aluminium structures*.

2 Normative references

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 See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. through "should" clauses) and permissions (i.e. through "may" clauses).

EN 1990, *Eurocode — Basis of structural design*

EN 1999-1-1:2023, *Eurocode 9 — Design of aluminium structures — Part 1-1: General rules*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, EN 1999-1-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1 Structural forms and geometry

3.1.1.1
shell
thin-walled body shaped as a curved surface with the thickness measured normal to the surface being small compared to the dimensions in the other directions

Note 1 to entry: A shell carries its loads mainly by membrane forces. The middle surface may have finite radius of curvature at each point or infinite radius of curvature in one direction, e.g. cylindrical shell.

Note 2 to entry: In EN 1999-1-5, a shell is an aluminium structure or structural component formed from curved sheets or extrusions.

3.1.1.2
shell of revolution
shell composed of a number of parts, each of which is a complete axisymmetric shell

3.1.1.3
complete axisymmetric shell
shell whose form is defined by a meridional generator line rotated around a single axis through 360°

Note 1 to entry: The shell can be of any length.

3.1.1.4
shell segment
part of shell of revolution in the form of a defined shell geometry with a constant wall thickness

Note 1 to entry: Examples are a cylinder, a conical frustum, a spherical frustum, an annular plate.

3.1.1.5
shell panel
incomplete axisymmetric shell where the shell form is defined by a rotation of the generator about the axis through less than 360°

3.1.1.6
middle surface
surface that lies midway between the inside and outside surfaces of a shell at every point

Note 1 to entry: If the shell is stiffened on only one surface, the reference middle surface is still taken as the middle surface of the curved shell plate. The middle surface is the reference surface for analysis, and can be discontinuous at changes of thickness or shell junctions, leading to eccentricities that are important to the shell response.

3.1.1.7
junction
point at which two or more shell segments meet

Note 1 to entry: It can include a stiffener or not: the point of attachment of a ring stiffener to the shell can be treated as a junction.

3.1.1.8
stringer stiffener
local stiffening member that follows the meridian of the shell, representing a generator of the shell of revolution

Note 1 to entry: It is provided to increase stability, or to assist with the introduction of local loads. It is not intended to provide a primary resistance for bending due to transverse loads.

3.1.1.9
ring stiffener
local stiffening member that passes around the circumference of the shell of revolution at a given point on the meridian

Note 1 to entry: It is assumed to have no stiffness in the meridional plane of the shell. It is provided to increase the stability or to introduce axisymmetric local loads acting in the plane of the ring by a state of axisymmetric normal forces. It is not intended to provide primary resistance to bending.

3.1.1.10
base ring
structural member that passes around the circumference of the shell of revolution at the base and provides means of attachment of the shell to a foundation or other element

Note 1 to entry: It is needed to ensure that the assumed boundary conditions are achieved in practice.

3.1.2 Special definitions for buckling calculations

3.1.2.1
critical buckling load
smallest bifurcation or limit load determined assuming the idealised conditions of elastic material behaviour, perfect geometry, perfect load application, perfect support, material isotropy and absence of residual stresses (LBA analysis)

3.1.2.2
critical buckling stress
nominal membrane stress associated with the elastic critical buckling load

3.1.2.3
characteristic buckling stress
nominal membrane stress associated with buckling in the presence of inelastic material behaviour and of geometrical and structural imperfections

3.1.2.4
design buckling stress
design value of the buckling stress, obtained by dividing the characteristic buckling stress by the partial factor for resistance

3.1.2.5
key value of the stress
value of stress in a non-uniform stress field that is used to characterise the stress magnitude in the buckling limit state assessment

3.1.2.6
tolerance class
class of requirements to geometrical tolerances for work execution

Note 1 to entry: Geometrical tolerances for work execution are built up from fabrication of components and execution of the components *in situ*.

3.2 Symbols

For the purposes of this document, the symbols given in EN 1999-1-1 and the following apply.

NOTE Additional symbols are defined where they occur.

Latin upper-case letters

C coefficient in buckling strength assessment;

C_{ϕ} sheeting stretching stiffness in the axial direction;

C_{θ} sheeting stretching stiffness in the circumferential direction;

$C_{\phi\theta}$ sheeting stretching stiffness in membrane shear;

D_{ϕ} sheeting flexural rigidity in the axial direction;

D_{θ} sheeting flexural rigidity in the circumferential direction;

$D_{\phi\theta}$ sheeting twisting flexural rigidity in twisting;

L total length of shell;

P_{n} load per unit circumference normal to the shell;

P_{x} load per unit circumference acting in the meridional direction;

P_{θ} load per unit circumference acting circumferentially on the shell;

U_{r} out-of-roundness tolerance parameter;

U_{0} initial dent tolerance parameter;

Latin lower-case letters

$a_{(...)}$	imperfection reduction factor in buckling strength assessment;
d	internal diameter of shell;
e	eccentricity between the middle surfaces of joined plates;
f_{eq}	von Mises equivalent strength;
f_u	characteristic value of ultimate tensile strength;
f_o	characteristic value of 0,2 % proof strength;
k	calibration factor for nonlinear analyses;
$k_{(...)}$	power of interaction Formulae in buckling strength interaction Formulae;
l	length of shell segment;
l_g	gauge length for measurement of imperfections;
$l_{g,\theta}$	gauge length for measurement of imperfections in circumferential direction;
$l_{g,w}$	gauge length for measurement of imperfections across welds;
l_R	limited length of shell for buckling strength assessment;
m_x	meridional bending moment per unit width, see Figure 3.2;
$m_{x,Ed}$	design values of the meridional bending moment per unit width;
m_θ	circumferential bending moment per unit width, see Figure 3.2,;
$m_{\theta,Ed}$	design values of the circumferential bending moment per unit width;
$m_{x\theta}$	twisting shear moment per unit width, see Figure 3.2;
$m_{x\theta,Ed}$	design values of the twisting shear moment per unit width;
n_x	meridional membrane axial force per unit length, see Figure 3.2;
$n_{x,Ed}$	design values of the meridional membrane axial force per unit length;
$n_{x\theta}$	membrane shear force per unit length, see Figure 3.2;
$n_{x\theta,Ed}$	design values of the membrane shear force per unit length ;
n_θ	circumferential membrane axial force per unit length, see Figure 3.2;
$n_{\theta,Ed}$	design values of the circumferential membrane axial force per unit length ;
p_n	pressure normal to the shell, see Figure 3.1;
p_x	meridional surface loading parallel to the shell, see Figure 3.1;
p_θ	circumferential surface loading parallel to the shell, see Figure 3.1;
r	radial coordinate of the middle surface, normal to the axis of revolution;
t	thickness of shell wall;
t_{max}	maximum thickness of shell wall at a joint;