

**EUROKODEKS 3: TERASKONSTRUKTSIOONIDE  
PROJEKTEERIMINE. OSA 4-1: PUISTEMAHUTID.**

**Eurocode 3 - Design of steel structures - Part 4-1: Silos**

**EESTI STANDARDI EESSÕNA****NATIONAL FOREWORD**

See Eesti standard EVS-EN 1993-4-1:2007+A1+NA:2018 sisaldab Euroopa standardi EN 1993-4-1:2007, selle paranduse AC:2009, muudatuse A1:2016 ja rahvusliku lisa NA:2018 ingliskeelset teksti.	This Estonian standard EVS-EN 1993-4-1:2007+A1+NA:2018 consists of the English text of the European standard EN 1993-4-1:2007, its corrigendum AC:2009, amendment A1:2017 and national annex NA:2018.
Standard on jõustunud sellekohase teate avaldamisega EVS Teatajas.	This standard has been endorsed with a notification published in the official bulletin of the Estonian Centre for Standardisation.
Euroopa standardimisorganisatsioonid on teinud Euroopa standardi rahvuslikele liikmetele kättesaadavaks 28.02.2007, muudatuse A1 28.06.2017.	Date of Availability of the European standard is 28.02.2007, for A1 28.06.2017.
Standard on kättesaadav Eesti Standardikeskusest.	The standard is available from the Estonian Centre for Standardisation.

Tagasisidet standardi sisu kohta on võimalik edastada, kasutades EVS-i veebilehel asuvat tagasiside vormi või saates e-kirja meiliaadressile [standardiosakond@evs.ee](mailto:standardiosakond@evs.ee).

ICS 65.040.20, 91.010.30, 91.080.13

**Standardite reprodutseerimise ja levitamise õigus kuulub Eesti Standardikeskusele**

Andmete paljundamine, taastekitamine, kopeerimine, salvestamine elektroonsesse süsteemi või edastamine ükskõik millises vormis või millisel teel ilma Eesti Standardikeskuse kirjaliku loata on keelatud.

Kui Teil on küsimusi standardite autorikaitse kohta, võtke palun ühendust Eesti Standardikeskusega:  
Koduleht [www.evs.ee](http://www.evs.ee); telefon 605 5050; e-post [info@evs.ee](mailto:info@evs.ee)

**The right to reproduce and distribute standards belongs to the Estonian Centre for Standardisation**

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, without a written permission from the Estonian Centre for Standardisation.

If you have any questions about copyright, please contact Estonian Centre for Standardisation:

Homepage [www.evs.ee](http://www.evs.ee); phone +372 605 5050; e-mail [info@evs.ee](mailto:info@evs.ee)

English Version

**Eurocode 3 - Design of steel structures - Part 4-1: Silos**

Eurocode 3 - Calcul des structures en acier - Partie 4-1:  
Silos

Eurocode 3 - Bemessung und Konstruktion von  
Stahlbauten - Teil 4-1: Silos

This European Standard was approved by CEN on 12 June 2006.

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

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



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

**Management Centre: rue de Stassart, 36 B-1050 Brussels**

## Contents

<b>Foreword</b>	<b>4</b>
<b>1 General</b>	<b>9</b>
1.1 Scope	9
1.2 Normative references	9
1.3 Assumptions	10
1.4 Distinction between principles and application rules	10
1.5 Terms and definitions	10
1.6 Symbols used in Part 4.1 of Eurocode 3	13
1.7 Sign conventions	15
1.8 Units	20
<b>2 Basis of design</b>	<b>20</b>
2.1 Requirements	20
2.2 Reliability differentiation	20
2.3 Limit states	21
2.4 Actions and environmental effects	22
2.5 Material properties	22
2.6 Geometrical data	22
2.7 Modelling of the silo for determining action effects	22
2.8 Design assisted by testing	22
2.9 Action effects for limit state verifications	23
2.10 Durability	24
2.11 Fire resistance	24
<b>3 Properties of materials</b>	<b>25</b>
3.1 General	25
3.2 Structural steels	25
3.3 Stainless steels	25
3.4 Special alloy steels	25
3.5 Toughness requirements	26
<b>4 Basis for structural analysis</b>	<b>27</b>
4.1 Ultimate limit states	27
4.2 Analysis of the structure of a shell silo	28
4.3 Analysis of the box structure of a rectangular silo	31
4.4 Equivalent orthotropic properties of corrugated sheeting	32
<b>5 Design of cylindrical walls</b>	<b>35</b>
5.1 Basis	35
5.2 Distinctions between cylindrical shell forms	35
5.3 Resistance of silo cylindrical walls	36
5.4 Special support conditions for cylindrical walls	59
5.5 Detailing for openings in cylindrical walls	64
5.6 Serviceability limit states	65
<b>6 Design of conical hoppers</b>	<b>66</b>
6.1 Basis	66
6.2 Distinctions between hopper shell forms	66
6.3 Resistance of conical hoppers	67
6.4 Considerations for special hopper structures	72
6.5 Serviceability limit states	73

<b>7</b>	<b>Design of circular conical roof structures</b>	<b>75</b>
7.1	Basis	75
7.2	Distinctions between roof structural forms	75
7.3	Resistance of circular conical silo roofs	75
<b>8</b>	<b>Design of transition junctions and supporting ring girders</b>	<b>77</b>
8.1	Basis	77
8.2	Analysis of the junction	80
8.3	Structural resistances	86
8.4	Limit state verifications	90
8.5	Considerations concerning support arrangements for the junction	92
<b>9</b>	<b>Design of rectangular and planar-sided silos</b>	<b>94</b>
9.1	Basis	94
9.2	Classification of structural forms	94
9.3	Resistance of unstiffened vertical walls	95
9.4	Resistance of silo walls composed of stiffened and corrugated plates	95
9.5	Silos with internal ties	100
9.6	Strength of pyramidal hoppers	100
9.7	Vertical stiffeners on box walls	102
9.8	Serviceability limit states	102
<b>Annex A: [Informative]</b>		<b>104</b>
<b>Simplified rules for circular silos in Consequence Class 1</b>		<b>104</b>
A.1	Action combinations for Consequence Class 1	104
A.2	Action effect assessment	104
A.3	Ultimate limit state assessment	104
<b>Annex B: [Informative]</b>		<b>111</b>
<b>Expressions for membrane stresses in conical hoppers</b>		<b>111</b>
<b>Annex C: [Informative]</b>		<b>113</b>
<b>Distribution of wind pressure around circular silo structures</b>		<b>113</b>

## Foreword

This European Standard EN 1993-4-1, “Eurocode 3: Design of steel structures – Part 4-1: Silos”, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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 August 2007 and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-4-1:1999.

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

## Background of the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980's.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement<sup>1)</sup> between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN1990	Eurocode: Basis of structural design
EN1991	Eurocode 1: Actions on structures
EN1992	Eurocode 2: Design of concrete structures
EN1993	Eurocode 3: Design of steel structures
EN1994	Eurocode 4: Design of composite steel and concrete structures
EN1995	Eurocode 5: Design of timber structures

<sup>1)</sup> Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

EN1996	Eurocode 6: Design of masonry structures
EN1997	Eurocode 7: Geotechnical design
EN1998	Eurocode 8: Design of structures for earthquake resistance
EN1999	Eurocode 9: Design of aluminium structures

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

### **Status and field of application of Eurocodes**

The Member States of the EU and EFTA recognise that EUROCODES serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 - Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire ;
- as a basis for specifying contracts for construction works and related engineering services ;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents<sup>2)</sup> referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards<sup>3)</sup>. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

### **National Standards implementing Eurocodes**

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National Annex.

The National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e. :

---

<sup>2)</sup> According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for harmonised ENs and ETAGs/ETAs.

<sup>3)</sup> According to Art. 12 of the CPD the interpretative documents shall :

- a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;
- b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc. ;
- c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, de facto, play a similar role in the field of the ER 1 and a part of ER 2.

- values and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc), e.g. snow map,
- the procedure to be used where alternative procedures are given in the Eurocode.

It may also contain:

- decisions on the application of informative annexes,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

### **Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products**

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works<sup>4)</sup>. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

### **Additional information specific to EN1993-4-1**

EN 1993-4-1 gives design guidance for the structural design of silos.

EN 1993-4-1 gives design rules that supplement the generic rules in the many parts of EN 1993-1.

EN 1993-4-1 is intended for clients, designers, contractors and relevant authorities.

EN 1993-4-1 is intended to be used in conjunction with EN 1990, with EN 1991-4, with the other Parts of EN 1991, with EN 1993-1-6 and EN 1993-4-2, with the other Parts of EN 1993, with EN 1992 and with the other Parts of EN 1994 to EN 1999 relevant to the design of silos. Matters that are already covered in those documents are not repeated.

Numerical values for partial factors and other reliability parameters are recommended as basic values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and quality management applies.

Safety factors for 'product type' silos (factory production) can be specified by the appropriate authorities. When applied to 'product type' silos, the factors in 2.10 are for guidance purposes only. They are provided to show the likely levels needed to achieve consistent reliability with other designs.

### **National Annex for EN1993-4-1**

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-4-1 should have a National Annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1993-4-1 through:

- 2.2 (1)
- 2.2 (3)

---

<sup>4)</sup> see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.



- 2.9.2.2 (3)
- 3.4 (1)
- 4.1.4 (2) and (4)
- 4.2.2.3 (6)
- 4.3.1 (6) and (8)
- 5.3.2.3 (3)
- 5.3.2.4 (10), (12) and (15)
- 5.3.2.5 (10) and (14)
- 5.3.2.6 (3) and (6)
- 5.3.2.8 (2)
- 5.3.3.5 (1) and (2)
- 5.3.4.3.2 (2)
- 5.3.4.3.3 (2) and (5)
- 5.3.4.3.4 (5)
- 5.3.4.5 (3)
- 5.4.4 (2), (3) and (4)
- 5.4.7 (3)
- 5.5.2 (3)
- 5.6.2 (1) and (2)
- 6.1.2 (4)
- 6.3.2.3 (2) and (4)
- 6.3.2.7 (3)
- 7.3.1 (4)
- 8.3.3 (4)
- 8.4.1 (6)
- 8.4.2 (5)
- 8.5.3 (3)
- 9.5.1 (3) and (4)
- 9.5.2 (5)
- 9.8.2 (1) and (2)
- A.2 (1) and (2)
- A.3.2.1 (6)
- A.3.2.2 (6)
- A.3.2.3 (2)
- A.3.3 (1), (2) and (3)
- A.3.4 (4)

# 1 General

## 1.1 Scope

- (1) Part 4.1 of Eurocode 3 provides principles and application rules for the structural design of steel silos of circular or rectangular plan-form, being free standing or supported.
- (2) The provisions given in this Part supplement modify or supersede the equivalent provisions given in EN 1993-1.
- (3) This part is concerned only with the requirements for resistance and stability of steel silos. For other requirements (such as operational safety, functional performance, fabrication and erection, quality control, details like man-holes, flanges, filling devices, outlet gates and feeders etc.), see the relevant standards.
- (4) Provisions relating to special requirements of seismic design are provided in EN 1998-4, which complements or adapts the provisions of Eurocode 3 specifically for this purpose.
- (5) The design of supporting structures for the silo are dealt with in EN 1993-1-1. The supporting structure is deemed to consist of all structural elements beneath the bottom flange of the lowest ring of the silo, see figure 1.1.
- (6) Foundations in reinforced concrete for steel silos are dealt with in EN 1992 and EN 1997.
- (7) Numerical values of the specific actions on steel silos to be taken into account in the design are given in EN 1991-4 Actions in Silos and Tanks.
- (8) This Part 4.1 does not cover:
  - resistance to fire;
  - silos with internal subdivisions and internal structures;
  - silos with capacity less than 10 tonnes;
  - cases where special measures are necessary to limit the consequences of accidents.
- (9) Where this standard applies to circular planform silos, the geometric form is restricted to axisymmetric structures, but the actions on them may be unsymmetrical, and their supports may induce forces in the silo that are not axisymmetrical.

## 1.2 Normative references

This European Standard incorporates, by dated and undated reference, provisions from other standards. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to, or revisions of, any of these publications apply to the European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 1090	<i>Execution of steel structures;</i>
EN 1990	<i>Eurocode: Basis of design;</i>
EN 1991	<i>Eurocode 1: Actions on structures;</i>
Part 1.1	<i>Actions on structures – Densities, self-weight and imposed loads for buildings;</i>
Part 1.2:	<i>Actions on structures – Actions on structures exposed to fire;</i>
Part 1.3:	<i>Actions on structures – Snow loads;</i>
Part 1.4:	<i>Actions on structures – Wind loads;</i>

Part 1.5:	<i>Actions on structures – Thermal loads;</i>
Part 1.6:	<i>Actions on structures – Construction loads;</i>
Part 1.5:	<i>Actions on structures – Accidental actions;</i>
Part 4:	<i>Actions on silos and tanks;</i>
EN 1993	<i>Eurocode 3: Design of steel structures;</i>
Part 1.1:	<i>General rules and rules for buildings;</i>
Part 1.3:	<i>Cold formed thin gauge members and sheeting;</i>
Part 1.4:	<i>Stainless steels;</i>
Part 1.6:	<i>Strength and stability of shell structures;</i>
Part 1.7:	<i>Planar plated structures loaded transversely;</i>
Part 1.8:	<i>Design of joints;</i>
Part 1.9:	<i>Fatigue strength of steel structures;</i>
Part 1.10:	<i>Selection of steel for fracture toughness and through-thickness properties;</i>
Part 4.2:	<i>Tanks;</i>
EN 1997	<i>Eurocode 7: Geotechnical design;</i>
EN 1998	<i>Eurocode 8: Design provisions for earthquake resistance of structures;</i>
Part 4:	<i>Silos, tanks and pipelines;</i>
EN 10025	<i>Hot rolled products of non-alloy structural steels - technical delivery conditions;</i>
EN 10147	<i>Hot-rolled flat products made of high yield strength steels for cold forming;</i>
ISO 1000	<i>SI Units;</i>
ISO 3898	<i>Bases for design of structures - Notation - General symbols;</i>
ISO 4997	<i>Cold reduced steel sheet of structural quality;</i>
ISO 8930	<i>General principles on reliability for structures - List of equivalent terms.</i>

### 1.3 Assumptions

- (1) In addition to the general assumptions of EN 1990 the following assumptions apply:
- fabrication and erection complies with EN 1090-2

### 1.4 Distinction between principles and application rules

- (1) See 1.4 in EN 1990.

### 1.5 Terms and definitions

- (1) The terms that are defined in 1.5 in EN 1990 for common use in the Structural Eurocodes and the definitions given in ISO 8930 apply to this Part 4.1 of EN 1993, unless otherwise stated, but for the purposes of this Part 4.1 the following supplementary definitions are given:

**1.5.1 shell.** A structure formed from a curved thin plate.