SLOVENSKI STANDARD

SIST EN 1998-4:2006

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Evrokod 8: Projektiranje potresnoodpornih konstrukcij – 4. del: Silosi, rezervoarji in cevovodi

Eurocode 8 - Design of structures for earthquake resistance - Part 4: Silos, tanks and pipelines

Eurocode 8 - Auslegung von Bauwerken gegen Erdbeben - Teil 4: Silos, Tankbauwerke und Rohrleitungen

Eurocode 8 - Calcul des structures pour leur résistance aux séismes - Partie 4: Silos, réservoirs et canalisations

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Eurocode 8 - Calcul des structures pour leur résistance aux séismes - Partie 4: Silos, réservoirs et canalisations

Eurocode 8 - Auslegung von Bauwerken gegen Erdbeben - Teil 4: Silos, Tankbauwerke und Rohrleitungen

This European Standard was approved by CEN on 15 May 2006.

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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 Central Secretariat has the same status as the official versions.

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Foreword

This European Standard EN 1998-4, Eurocode 8: Design of structures for earthquake resistance: Silos, tanks and pipelines, has been prepared by Technical Committee CEN/TC 250 "Structural Eurocodes", the secretariat of which is held by BSI. CEN/TC 250 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of an identical text or by endorsement, at the latest by January 2007, and conflicting national standards shall be withdrawn at latest by March 2010.

This document supersedes ENV 1998-4: 1997.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, 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 harmonization of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonized 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[1] between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to 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:

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

EN 1990 Eurocode: Basis of structural 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

Eurocode standards recognize 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 recognize 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 harmonized 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[2] referred to in Article 12 of the CPD, although they are of a different nature from harmonized product standards[3]. Therefore, technical

[2] 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 hENs and ETAGs/ETAs.

[3] 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, etB. ;

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.

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 a 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 (informative).

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. :

– 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 harmonized technical specifications (ENs and ETAs) for products

There is a need for consistency between the harmonized technical specifications for construction products and the technical rules for works[4]. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN 1998-4

The scope of EN 1998 is defined in **1.1.1** of EN 1998-1: 2004. The scope of this Part of EN 1998 is defined in **1.1**. Additional Parts of Eurocode 8 are listed in EN 1998-1: 2004, **1.1.3**.

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[4] 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.

EN 1998-4:2006 is intended for use by:

- clients (e.g. for the formulation of their specific requirements on reliability levels and durability) ;
- designers and constructors ;
- relevant authorities.

For the design of structures in seismic regions the provisions of this European Standard are to be applied in addition to the provisions of the other relevant parts of Eurocode 8 and the other relevant Eurocodes. In particular, the provisions of this European Standard complement those of EN 1991-4, EN 1992-3, EN 1993-4-1, EN 1993-4-2 and EN 1993-4-3, which do not cover the special requirements of seismic design.

National annex for EN 1998-4

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 1998-4 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 1998-4:2006 through clauses:

Reference	Item
1.1(4)	Additional requirements for facilities associated with large risks to the population or the environment.
2.1.2(4)P	Reference return period T_{NCR} of seismic action for the ultimate limit state (or, equivalently, reference probability of exceedance in 50 years, P_{NCR}).
2.1.3(5)P	Reference return period T_{DLR} of seismic action for the damage limitation state (or, equivalently, reference probability of exceedance in 10 years, P_{DLR}).
2.1.4(8)	Importance factors for silos, tanks and pipelines
2.2(3)	Reduction factor ν for the effects of the seismic action relevant to the damage limitation state
2.3.3.3(2)P	Maximum value of radiation damping for soil structure interaction analysis, ξ_{max}
2.5.2(3)P	Values of φ for silos, tanks and pipelines
3.1(2)P	Unit weight of the particulate solid in silos, γ, in the seismic design situation
4.5.1.3(3)	Amplification factor on forces transmitted by the piping to region of attachment on the tank wall, for the design of the region to remain elastic in the damage limitation state
4.5.2.3(2)P	Overstrength factor on design resistance of piping in the verification that the connection of the piping to the tank will not yield prior to the piping in the ultimate limit state

1 GENERAL

1.1 Scope

(1) The scope of Eurocode 8 is defined in EN 1998-1: 2004, **1.1.1** and the scope of this Standard is defined in this clause. Additional parts of Eurocode 8 are indicated in EN 1998-1: 2004, **1.1.3**.

(2) This standard specifies principles and application rules for the seismic design of the structural aspects of facilities composed of above-ground and buried pipeline systems and of storage tanks of different types and uses, as well as for independent items, such as for example single water towers serving a specific purpose or groups of silos enclosing granular materials, etc.

(3) This standard includes the additional criteria and rules required for the seismic design of these structures without restrictions on their size, structural types and other functional characteristics. For some types of tanks and silos, it also provides detailed methods of assessment and verification rules.

(4) This standard may not be complete for those facilities associated with large risks to the population or the environment, for which additional requirements are the responsibility of the competent authorities. This standard is also not complete for those construction works which have uncommon structural elements and which require special measures to be taken and special studies to be performed to ensure earthquake protection. In those two cases the present standard gives general principles but not detailed application rules.

NOTE The National Annex may specify additional requirements for facilities associated with large risks to the population or the environment.

(5) Although large diameter pipelines are within the scope of this standard, the corresponding design criteria do not apply for apparently similar facilities, like tunnels and large underground cavities.

(6) The nature of lifeline systems which often characterizes the facilities covered by this standard requires concepts, models and methods that may differ substantially from those in current use for more common structural types. Furthermore, the response and the stability of silos and tanks subjected to strong seismic actions may involve rather complex interaction phenomena between soil-structure and stored material (either fluid or granular), not easily amenable to simplified design procedures. Equally challenging may prove to be the design of a pipeline system through areas with poor and possibly unstable soils. For the reasons given above, the organization of this standard is to some extent different from that of other Parts of EN 1998. This standard is, in general, restricted to basic principles and methodological approaches.

NOTE Detailed analysis procedures going beyond basic principles and methodological approaches are given in Annexes A and B for a number of typical situations.

(7) In the formulation and implementation of the general requirements, a distinction has been made between independent structures and redundant systems, via the choice of importance factors and/or through the definition of specific verification criteria.

(8) If seismic protection of above-ground pipelines is provided through seismic isolation devices between the pipeline and its supports (notably on piles), EN 1998-2:2005 applies, as relevant. For the design of tanks, silos, or individual facilities or components of pipeline systems with seismic isolation, the relevant provisions of EN 1998-1:2004 apply.

1.2 Normative references

(1)P This European Standard incorporates by dated or undated reference, provisions from other publications. 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 this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

1.2.1 General reference standards

EN 1990: 2002 *Eurocode - Basis of structural design.*

EN 1991-4: 2006 *Eurocode 1 - Actions on structures – Part 4: Silos and tanks.*

EN 1992-1-1: 2004 *Eurocode 2 - Design of concrete structures – Part 1-1: General rules and rules for buildings.*

EN 1992-3: 2006 *Eurocode 2 - Design of concrete structures – Part 3: Liquid retaining and containing structures.*

EN 1993-1-1: 2004 *Eurocode 3 - Design of steel structures – Part 1-1: General rules and rules for buildings.*

EN 1993-1-5: 2006 *Eurocode 3 - Design of steel structures – Part 1-5: Plated structural elements.*

EN 1993-1-6: 2006 *Eurocode 3 - Design of steel structures – Part 1-6: Strength and stability of shell structures.*

EN 1993-1-7: 2006 *Eurocode 3 - Design of steel structures – Part 1-7: Strength and stability of planar plated structures transversely loaded.*

EN 1993-4-1: 2006 *Eurocode 3 - Design of steel structures – Part 4-1: Silos.*

EN 1993-4-2: 2006 *Eurocode 3 - Design of steel structures – Part 4-2: Tanks.*

EN 1993-4-3: 2006 *Eurocode 3 - Design of steel structures – Part 4-3: Pipelines.*

EN 1997-1 : 2004 *Eurocode 7 - Geotechnical design – Part 1: General rules.*

EN 1998-1 : 2004 *Eurocode 8 - Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings.*

EN 1998-2 : 2005 *Eurocode 8 - Design of structures for earthquake resistance – Part 2: Bridges.*

EN 1998-5 : 2004 *Eurocode 8 - Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects.*

EN 1998-6 : 2005 *Eurocode 8 - Design of structures for earthquake resistance – Part 6: Towers, masts and chimneys.*

1.3 Assumptions

(1)P The general assumptions shall be in accordance with EN 1990: 2002, **1.3**.

1.4 Distinction between principles and applications rules

(1)P The distinction between principles and applications rules shall be in accordance with EN 1990: 2002, **1.4**.

1.5 Terms and Definitions

1.5.1 General

(1) For the purposes of this standard the following definitions apply.

1.5.2 Terms common to all Eurocodes

(1)P The terms and definitions given in EN 1990: 2002, **1.5** apply.

(2)P EN 1998-1: 2004, **1.5.1** applies for terms common to all Eurocodes.

1.5.3 Further terms used in EN 1998

(1) For the purposes of this European Standard the terms given in EN 1998-1: 2004, **1.5.1** and **1.5.2** apply.

1.5.4 Further terms used in EN 1998-4

Independent structure:
a structure whose structural and functional behaviour during and after a seismic event are not influenced by that of other structures, and whose consequences of failure relate only to the functions demanded from it.

1.6 Symbols

(1) For the purposes of this European Standard the following symbols apply:

A_{Ed} design value of seismic action (= $\gamma_I A_{Ek}$)

A_{Ek} characteristic value of the seismic action for the reference return period

b horizontal dimension of silo parallel to the horizontal component of the seismic action

d_c inside diameter of a circular silo

d_g design ground displacement, as given in EN 1998-1:2004, **3.2.2.4(1)**, used in expression (4.1)

g acceleration of gravity

h_b overall height of the silo, from a flat bottom or the hopper outlet to the equivalent surface of the stored contents

q behaviour factor

r radius of circular silo, silo compartment, tank or pipe

r_s* geometric quantity defined in silos through expression (3.5) as $r_s^* = \min(H, Br_s/2)$

t thickness

x vertical distance of a point on a silo wall from a flat silo bottom or the apex of a conical or pyramidal hopper

x distance between the anchoring point of piping and the point of connection with the tank

z vertical downward co-ordinate in a silo, measured from the equivalent surface of the stored contents

$\alpha(z)$ ratio of the response acceleration of a silo at the level of interest, z, to the acceleration of gravity

β angle of inclination of the hopper wall in a silo, measured from the vertical, or the steepest angle of inclination to the vertical of the wall in a pyramidal hopper

γ bulk unit weight of particulate material in silo, taken equal to the upper characteristic value given in EN 1991-4:2006, Table E1.

γ_I importance factor

γ_p amplification factor on forces transmitted by the piping to region of attachment on tank wall, for the region to be designed to remain elastic, see **4.5.1.3(3)**

Δ minimum value of imposed relative displacement between the first anchoring point of piping and the tank to be taken from given by expression (4.1)

$\Delta_{ph,s}$ additional normal pressure on the silo wall due to the response of the particulate solid to the horizontal component of the seismic action

$\Delta_{ph,so}$ reference pressure on silo walls given in **3.3(8)**, expression (3.6)

θ angle ($0^o \leq \theta < 360^o$) between the radial line to the point of interest on the wall of a circular silo and the direction of the horizontal component of the seismic action.

λ the correction factor on base shear from the lateral force method of analysis, in EN 1998-1: 2004, **4.3.3.2.2(1)**.

ν reduction factor for the effects of the seismic action relevant to the damage limitation state

ξ viscous damping ratio (in percent)

$\psi_{2,i}$ combination coefficient for the quasi-permanent value of a variable action i

$\psi_{E,i}$ combination coefficient for a variable action i, to be used when determining the effects of the design seismic action

1.7 S.I. Units

(1)P S.I. Units shall be used in accordance with ISO 1000.

(2) In addition, the units recommended in EN 1998-1:2004, **1.7** apply.

2 GENERAL PRINCIPLES AND APPLICATION RULES

2.1 Safety requirements

2.1.1 General

(1)P This standard deals with structures which may differ widely in such basic features as:

– the nature and amount of the contents and associated potential danger

– the functional requirements during and after the seismic event

– the environmental conditions.

(2) Depending on the specific combination of the indicated features, different formulations of the general requirements are appropriate. For the sake of consistency with the general framework of the Eurocodes, the two-limit-states format is retained, with a suitably adjusted definition.

2.1.2 Ultimate limit state

(1)P The ultimate limit state for which a system shall be checked is defined as that corresponding to structural failure. In some circumstances, partial recovery of the operational capacity of the system lost by exceedance of the ultimate limit state may be possible, after an acceptable amount of repairs.

NOTE 1: The circumstances are those defined by the responsible authority or the client.

(2)P For particular elements of the network, as well as for independent structures whose complete collapse would entail severe consequences, the ultimate limit state is defined as that of a state prior to structural collapse that, although possibly severe, would exclude brittle failures and would allow for a controlled release of the contents. When the failure of the aforementioned elements does not entail severe consequences, the ultimate limit state may be defined as corresponding to total structural collapse.

(3)P The design seismic action for which the ultimate limit state may not be exceeded shall be established based on the direct and indirect consequences of structural failure.

(4)P The design seismic action, A_{Ed}, shall be expressed in terms of: a) the reference seismic action, A_{Ek}, associated with a reference probability of exceedance, P_{NCR}, in 50 years or a reference return period, T_{NCR}, (see EN 1998-1:2004, **2.1(1)**P and **3.2.1(3)**) and b) the importance factor γ_I (see EN 1990:2002 and EN 1998-1:2004, **2.1(2)**P, **2.1(3)**P and **(4)**) to take into account reliability differentiation:

$$A_{Ed} = \gamma_I A_{Ek} \tag{2.1}$$

NOTE: The value to be ascribed to the reference return period, T_{NCR}, associated with the reference seismic action for use in a country, may be found in its National Annex. The recommended value is: T_{NCR} = 475 years.

(5) The capacity of structural systems to resist seismic actions at the ultimate limit state in