



Institut luxembourgeois de la normalisation
de l'accréditation, de la sécurité et qualité
des produits et services

ILNAS-EN 1998-4:2006

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

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

07/2006



National Foreword

This European Standard EN 1998-4:2006 was adopted as Luxembourgish Standard ILNAS-EN 1998-4:2006.

Every interested party, which is member of an organization based in Luxembourg, can participate for FREE in the development of Luxembourgish (ILNAS), European (CEN, CENELEC) and International (ISO, IEC) standards:

- Participate in the design of standards
- Foresee future developments
- Participate in technical committee meetings

<https://portail-qualite.public.lu/fr/normes-normalisation/participer-normalisation.html>

THIS PUBLICATION IS COPYRIGHT PROTECTED

Nothing from this publication may be reproduced or utilized in any form or by any mean - electronic, mechanical, photocopying or any other data carries without prior permission!

ILNAS-EN 1998-4:2006

EUROPEAN STANDARD **EN 1998-4**

NORME EUROPÉENNE

EUROPÄISCHE NORM

July 2006

ICS 91.120.25

Supersedes ENV 1998-4:1998

English Version

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

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.

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 Central Secretariat 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 Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, 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
FOREWORD

1	GENERAL	8
1.1	SCOPE	8
1.2	NORMATIVE REFERENCES	9
1.2.1	<i>General reference standards</i>	<i>9</i>
1.3	ASSUMPTIONS	10
1.4	DISTINCTION BETWEEN PRINCIPLES AND APPLICATIONS RULES	10
1.5	TERMS AND DEFINITIONS	10
1.5.1	<i>General.....</i>	<i>10</i>
1.5.2	<i>Terms common to all Eurocodes</i>	<i>10</i>
1.5.3	<i>Further terms used in EN 1998</i>	<i>10</i>
1.5.4	<i>Further terms used in EN 1998-4.....</i>	<i>10</i>
1.6	SYMBOLS	10
1.7	S.I. UNITS	11
2	GENERAL PRINCIPLES AND APPLICATION RULES.....	13
2.1	SAFETY REQUIREMENTS	13
2.1.1	<i>General.....</i>	<i>13</i>
2.1.2	<i>Ultimate limit state</i>	<i>13</i>
2.1.3	<i>Damage limitation state</i>	<i>14</i>
2.1.4	<i>Reliability differentiation</i>	<i>15</i>
2.1.5	<i>System versus element reliability.....</i>	<i>16</i>
2.1.6	<i>Conceptual design.....</i>	<i>16</i>
2.2	SEISMIC ACTION	17
2.3	ANALYSIS	17
2.3.1	<i>Methods of analysis.....</i>	<i>17</i>
2.3.2	<i>Interaction with the soil.....</i>	<i>18</i>
2.3.3	<i>Damping.....</i>	<i>19</i>
2.3.3.1	Structural damping	19
2.3.3.2	Contents damping	19
2.3.3.3	Foundation damping	19
2.3.3.4	Weighted damping.....	19
2.4	BEHAVIOUR FACTORS	19
2.5	SAFETY VERIFICATIONS	20
2.5.1	<i>General.....</i>	<i>20</i>
2.5.2	<i>Combinations of seismic action with other actions</i>	<i>20</i>
3	SPECIFIC PRINCIPLES AND APPLICATION RULES FOR SILOS.....	22
3.1	INTRODUCTION	22
3.2	COMBINATION OF GROUND MOTION COMPONENTS	22
3.3	ANALYSIS OF SILOS	23
3.4	BEHAVIOUR FACTORS	25
3.5	VERIFICATIONS	26
3.5.1	<i>Damage limitation state</i>	<i>26</i>
3.5.2	<i>Ultimate limit state</i>	<i>26</i>
3.5.2.1	Global stability	26
3.5.2.2	Shell.....	26
3.5.2.3	Anchors	27
3.5.2.4	Foundations	27
4	SPECIFIC PRINCIPLES AND APPLICATION RULES FOR TANKS.....	28
4.1	COMPLIANCE CRITERIA	28
4.1.1	<i>General.....</i>	<i>28</i>
4.1.2	<i>Damage limitation state</i>	<i>28</i>
4.1.3	<i>Ultimate limit state</i>	<i>28</i>
4.2	COMBINATION OF GROUND MOTION COMPONENTS	29

4.3	METHODS OF ANALYSIS	29
4.3.1	General.....	29
4.3.2	Hydrodynamic effects.....	29
4.4	BEHAVIOUR FACTORS	30
4.5	VERIFICATIONS.....	31
4.5.1	Damage limitation state	31
4.5.1.1	General	31
4.5.1.2	Shell.....	31
4.5.1.3	Piping	31
4.5.2	Ultimate limit state	31
4.5.2.1	Stability	31
4.5.2.2	Shell.....	31
4.5.2.3	Piping	32
4.5.2.4	Anchorage.....	32
4.5.2.5	Foundations	32
4.6	COMPLEMENTARY MEASURES.....	32
4.6.1	Bunding	32
4.6.2	Sloshing.....	33
4.6.3	Piping interaction.....	33
5	SPECIFIC PRINCIPLES AND APPLICATION RULES FOR ABOVE-GROUND PIPELINES	34
5.1	GENERAL	34
5.2	SAFETY REQUIREMENTS.....	34
5.2.1	Damage limitation state	34
5.2.2	Ultimate limit state	35
5.3	SEISMIC ACTION.....	35
5.3.1	General.....	35
5.3.2	Seismic action for inertia movements.....	35
5.3.3	Differential movement.....	35
5.4	METHODS OF ANALYSIS	35
5.4.1	Modelling	36
5.4.2	Analysis	36
5.5	BEHAVIOUR FACTORS	36
5.6	VERIFICATIONS.....	37
6	SPECIFIC PRINCIPLES AND APPLICATION RULES FOR BURIED PIPELINES	38
6.1	GENERAL	38
6.2	SAFETY REQUIREMENTS.....	38
6.2.1	Damage limitation state	38
6.2.2	Ultimate limit state	38
6.3	SEISMIC ACTION.....	38
6.3.1	General.....	38
6.3.2	Seismic action for inertia movements.....	39
6.3.3	Modelling of seismic waves.....	39
6.3.4	Permanent soil movements.....	39
6.4	METHODS OF ANALYSIS (WAVE PASSAGE)	40
6.5	VERIFICATIONS.....	40
6.5.1	General.....	40
6.5.2	Buried pipelines on stable soil	40
6.5.3	Buried pipelines under differential ground movements (welded steel pipes)	41
6.6	DESIGN MEASURES FOR FAULT CROSSINGS	41
	ANNEX A (INFORMATIVE).....	43
	SEISMIC ANALYSIS PROCEDURES FOR TANKS	43
	ANNEX B (INFORMATIVE).....	79
	BURIED PIPELINES	79

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 agreement¹ 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 Documents² referred to in Article 12 of the CPD, although they are of a different nature from harmonized product standards³. 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 works⁴. 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**.

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