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Eurokod 1: Laster på bärverk – Del 4: Silor och behållare

Eurocode 1: Actions on structures – Part 4: Silos and tanks

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SS-EN 1991-4:2006, utgåva 1 och SS-ENV 1991-4, utgåva 1, gäller parallellt längst till 2010-01-01.

The European Standard EN 1991-4:2006 has the status of a Swedish Standard. This document contains the official English version of EN 1991-4:2006.

SS-EN 1991-4:2006, edition 1 and SS-ENV 1991-4, edition 1, are valid for and run parallel longest to 2010-01-01.

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1991-4

May 2006

ICS 91.010.30

Supersedes ENV 1991-4:1995

English Version

Eurocode 1 - Actions on structures - Part 4: Silos and tanks

Eurocode 1 - Actions sur les structures - Partie 4: Silos et réservoirs

Eurocode 1 - Grundlagen der Tragwerksplanung und Einwirkungen auf Tragwerke - Teil 4: Silos und Flüssigkeitsbehälter

This European Standard was approved by CEN on 12 October 2005.

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.

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EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (EN 1991-4:2006) has been prepared by Technical Committee CEN/TC250 "Structural Eurocode", the secretariat of which is held by BSI.

This document shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2006, and conflicting national standards shall be withdrawn at the latest by March 2010.

This document supersedes ENV 1991-4:1995.

According to the CEN/CENELEC Internal Regulations, the national standards 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 the 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 1980s.

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 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
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

[1)] 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).

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 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.:

- 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:

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2) According to Article 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 harmonized ENs and ETAGs/ETAs.

3) According to Article 12 of the CPD the interpretative documents shall:

a) give concrete form to the essential requirements by harmonizing 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 harmonized 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.

- 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 EN1991-4

EN 1991-4 gives design guidance for the assessment of actions for the structural design of silos and tanks.

EN 1991-4 is intended for clients, designers, contractors and relevant authorities.

EN 1991-4 is intended to be used in conjunction with EN 1990, with the other parts of EN 1991, with EN 1992 and EN 1993, and with the other parts of EN 1994 to EN 1999 relevant to the design of silos and tanks.

National Annex for EN1991-4

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 1991-4 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 1991-4 through:

- 2.5 (5)
- 3.6 (2)
- 5.2.4.3.1 (3)
- 5.4.1 (3)
- 5.4.1 (4)
- A.4 (3)
- B.2.14 (1)

4) See Article 3.3 and Article 12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

Section 1 General

1.1 Scope

1.1.1 Scope of EN 1991 - Eurocode 1

(1)P EN 1991 provides general principles and actions for the structural design of buildings and civil engineering works including some geotechnical aspects and shall be used in conjunction with EN 1990 and EN 1992-1999.

(2) EN 1991 also covers structural design during execution and structural design for temporary structures. It relates to all circumstances in which a structure is required to give adequate performance.

(3) EN 1991 is not directly intended for the structural appraisal of existing construction, in developing the design of repairs and alterations or for assessing changes of use.

(4) EN 1991 does not completely cover special design situations which require unusual reliability considerations such as nuclear structures for which specified design procedures should be used.

1.1.2 Scope of EN 1991-4 actions on structures: silos and tanks

(1)P This part provides general principles and actions for the structural design of silos for the storage of particulate solids and tanks for the storage of fluids and shall be used in conjunction with EN 1990, other parts of EN 1991 and EN 1992 to EN 1999.

(2) This part includes some provisions for actions on silo and tank structures that are not only associated with the stored solids or liquids (e.g. the effects of thermal differentials, aspects of the differential settlements of batteries of silos)

(3) The following geometrical limitations apply to the design rules for silos:

– the silo cross-section shapes are limited to those shown in Figure 1.1d, though minor variations may be accepted provided the structural consequences of the resulting changes in pressure are considered;

– the following dimensional limitations apply:

$h_b/d_c < 10$
$h_b < 100$ m
$d_c < 60$ m

– the transition lies in a single horizontal plane (see Figure 1.1a);

– the silo does not contain an internal structure such as a cone or pyramid with its apex uppermost, cross-beams, etc. However, a rectangular silo may contain internal ties.

(4) The following limitations on the stored solids apply to the design rules for silos:

– each silo is designed for a defined range of particulate solids properties;

– the stored solid is free-flowing, or the stored solid can be guaranteed to flow freely within the silo container as designed (see 1.5.12 and Annex C);

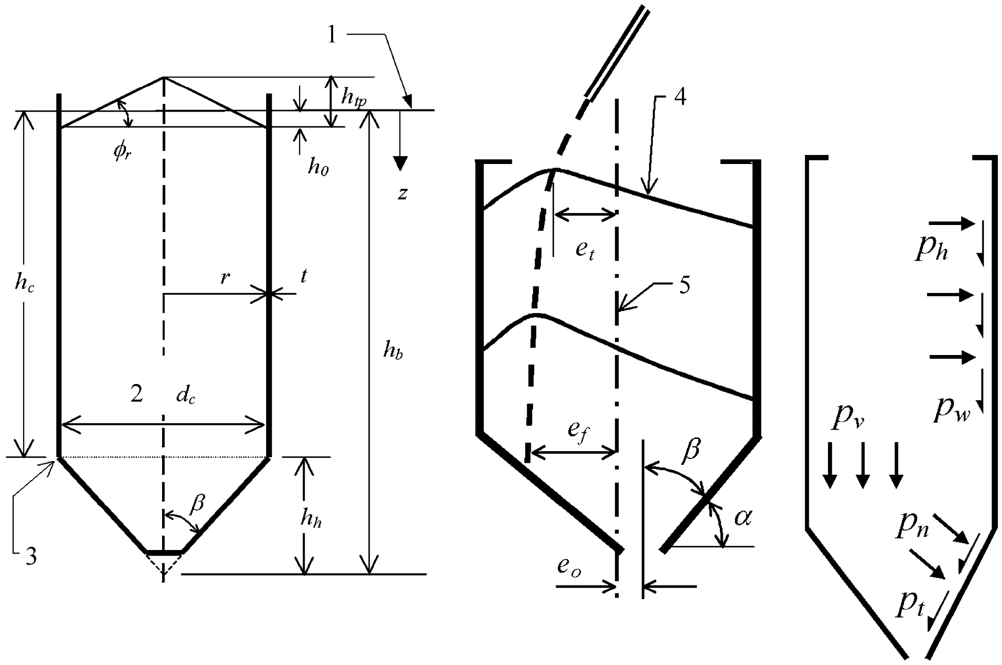
– the maximum particle diameter of the stored solid is not greater than $0{,}03d_c$ (see Figure 1.1d).

NOTE: When particles are large compared to the silo wall thickness, account should be taken of the effects of single particles applying local forces on the wall.

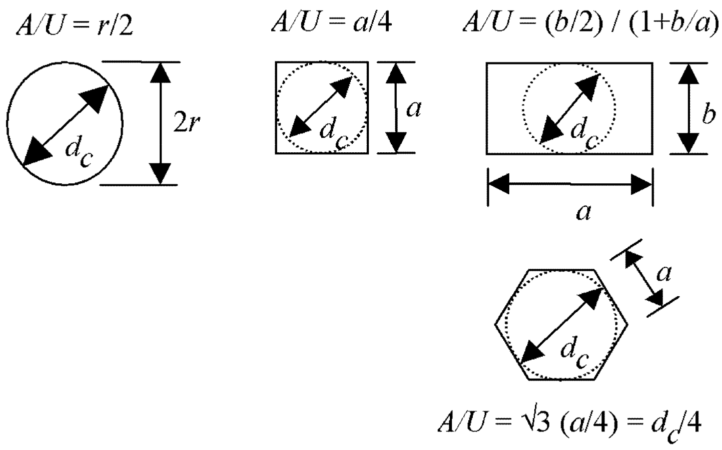
(5) The following limitations on the filling and discharge arrangements apply to the design rules for silos:

– filling involves only negligible inertia effects and impact loads;

– where discharge devices are used (for example feeders or internal flow tubes) solids flow is smooth and central.



a) Geometry **b) Eccentricities** **c) Pressures and tractions**



d) Cross-section shapes

Key

1 Equivalent surface
2 Inside dimension
3 Transition
4 Surface profile for full condition
5 Silo centre line

Figure 1.1: Silo forms showing dimensions and pressure notation

(6) Only hoppers that are conical (i.e. axisymmetric), square pyramidal or wedge-shaped (i.e. with vertical end walls) are covered by this standard. Other hopper shapes and hoppers with internals require special considerations.

(7) Some silos with a systematically non-symmetric geometry are not specifically covered by this standard. These cases include a chisel hopper (i.e. a wedge hopper beneath a circular cylinder) and a diamond-back hopper.

(8) The design rules for tanks apply only to tanks storing liquids at normal atmospheric pressure.

(9) Actions on the roofs of silos and tanks are given in EN 1991-1-1, EN 1991-1-3 to EN 1991-1-7 and EN 1991-3 as appropriate.

(10) The design of silos for reliable solids discharge is outside the scope of this standard.

(11) The design of silos against silo quaking, shocks, honking, pounding and silo music is outside the scope of this standard.

NOTE: These phenomena are not well understood, so the use of this standard does not guarantee that they will not occur, or that the structure is adequate to resist them.

1.2 Normative references

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 applies (including amendments).

ISO 3898:1997 Basis of design for structures: Notation. General symbols

NOTE: The following European Standards which are published or in preparation are cited at the appropriate places in the text:

EN 1990 Basis of structural design

EN 1991-1-1 Eurocode 1: Actions on structures: Part 1.1: Densities, self-weight and imposed loads

EN 1991-1-2 Eurocode 1: Actions on structures: Part 1.2: Actions on structures exposed to fire

EN 1991-1-3 Eurocode 1: Actions on structures: Part 1.3: Snow loads

EN 1991-1-4 Eurocode 1: Actions on structures: Part 1.4: Wind actions

EN 1991-1-5 Eurocode 1: Actions on structures: Part 1.5: Thermal actions

EN 1991-1-6 Eurocode 1: Actions on structures: Part 1.6: General actions. Actions during execution

EN 1991-1-7 Eurocode 1: Actions on structures: Part 1.7: Accidental actions

EN 1991-2 Eurocode 1: Actions on structures: Part 2: Traffic loads on bridges

EN 1991-3 Eurocode 1: Actions on structures: Part 3: Actions induced by cranes and machinery

EN 1992 Eurocode 2: Design of concrete structures

EN 1992-4 Eurocode 2: Design of concrete structures: Part 4: Liquid retaining and containment structures

EN 1993 Eurocode 3: Design of steel structures

EN 1993-1-6 Eurocode 3: Design of steel structures: General rules: Part 1.6: Supplementary rules for the strength and stability of shell structures

EN 1993-4-1	Eurocode 3: Design of steel structures: Part 4.1: Silos
EN 1993-4-2	Eurocode 3: Design of steel structures: Part 4.2: Tanks
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 alloy structures

1.3 Assumptions

(1)P The general assumptions given in EN 1990, 1.3 apply.

1.4 Distinction between principles and application rules

(1) Depending on the character of the individual paragraphs, distinction is made in this part between principles and application rules.

(2) The principles comprise:

– general statements and definitions for which there is no alternative, as well as

– requirements and analytical models for which no alternative is permitted unless specifically stated.

(3) The principles are identified by the letter P following the paragraph number.

(4) The application rules are generally recognized rules which follow the principles and satisfy their requirements.

(5) It is permissible to use alternative rules different from the application rules given in this Eurocode, provided it is shown that the alternative rules accord with the relevant principles and have at least the same reliability.

(6) In this part the application rules are identified by a number in parentheses, e.g. as this paragraph.

1.5 Definitions

For the purposes of this standard, a basic list of definitions is provided in EN 1990, 1.5 and the additional definitions given below are specific to this part.

1.5.1
aerated silo bottom
a silo base in which air slides or air injection is used to activate flow in the bottom of the silo (see figure 3.5b)

1.5.2
characteristic dimension of inside of silo cross-section
the characteristic dimension d_c is the diameter of the largest inscribed circle within the silo cross-section (see Figure 1.1d)

1.5.3
circular silo
a silo whose plan cross-section is circular (see Figure 1.1d)

1.5.4
cohesion
the shear strength of the stored solid when the normal stress on the failure plane is zero

1.5.5
conical hopper
a hopper in which the sloping sides converge towards a single point intended to produce axisymmetric flow in the stored solid

1.5.6
eccentric discharge
flow pattern in the stored solid arising from moving solid being unsymmetrically distributed relative to the vertical centreline of the silo. This normally arises as a result of an eccentrically located outlet (see Figures 3.2c and d, 3.3b and c), but can be caused by other unsymmetrical phenomena (see Figure 3.4d)

1.5.7
eccentric filling
a condition in which the top of the heap at the top of the stored solids at any stage of the filling process is not located on the vertical centreline of the silo (see Figure 1.1b)

1.5.8
equivalent surface
level surface giving the same volume of stored solid as the actual surface (see Figure 1.1a)

1.5.9
expanded flow hopper
a hopper in which the lower section of the hopper has sides sufficiently steep to cause mass flow, while the upper section of the hopper has shallow sides and funnel flow is expected (see Figure 3.5d). This expedient arrangement reduces the hopper height whilst assuring reliable discharge

1.5.10
flat bottom
the internal base of a silo, when it has an inclination to the horizontal less than 5°

1.5.11
flow pattern
the form of flowing solid in the silo when flow is well established (see Figures 3.1-3.4). The silo is close to the full condition

1.5.12
fluidized solid
a state of a stored fine particulate solid when its bulk contains a high proportion of interstitial air, with a pressure gradient that supports the weight of the particles. The air may be introduced either by aeration or by the filling process. A solid may be said to be partially fluidized when only part of the weight of particles is supported by the interstitial air pressure gradient

1.5.13
free flowing granular solid
a granular solid whose flowing behaviour is not significantly affected by cohesion

1.5.14
full condition
a silo is said to be in the full condition when the top surface of the stored solid is at the highest position considered possible under operating conditions during the design life-time of the structure. This is the assumed design condition for the silo

1.5.15
funnel flow
a flow pattern in which a channel of flowing solid develops within a confined zone above the outlet, and the solid adjacent to the wall near the outlet remains stationary (see Figure 3.1). The flow channel can intersect the vertical walled segment (mixed flow) or extend to the surface of the stored solid (pipe flow)

1.5.16
granular solid
a particulate solid in which all the particles are so large that interstitial air plays a small role in determining the pressures and flow of large masses of the solid

1.5.17
high filling velocity
the condition in a silo where the rapidity of filling can lead to entrainment of air within the stored solid to such an extent that the pressures applied to the walls are substantially changed from those without air entrainment

1.5.18
homogenizing fluidized silo
a silo in which the particulate solid is fluidized to assist blending

1.5.19
hopper
a silo bottom with inclined walls

1.5.20
hopper pressure ratio *F*
the ratio of the normal pressure p_n on the sloping wall of a hopper to the mean vertical stress p_v in the solid at the same level

1.5.21
intermediate slenderness silo
a silo where $1{,}0 < h_c/d_c < 2{,}0$ (except as defined in 3.3)

1.5.22
internal pipe flow
a pipe flow pattern in which the flow channel boundary extends to the surface of the stored solid without contact with the wall (see Figures 3.1 and 3.2)

1.5.23
lateral pressure ratio *K*
the ratio of the mean horizontal pressure on the vertical wall of a silo to the mean vertical stress in the solid at the same level

1.5.24
low cohesion
a particulate solid sample has low cohesion if the cohesion c is less than 4 % of the preconsolidation stress σ_r (a method for determining cohesion is given in C.9)

1.5.25
mass flow
a flow pattern in which all the stored particles are simultaneously in motion during discharge (see Figure 3.1a)

1.5.26
mixed flow
a funnel flow pattern in which the flow channel intersects the vertical wall of the silo at a point below the solid surface (see Figures 3.1c and 3.3)

1.5.27
non-circular silo
a silo whose plan cross-section is in any shape that is not circular (see Figure 1.1d)

1.5.28
particulate solid
a solid in the form of many discrete and independent particles

1.5.29
patch load
a local load taken to act over a specified zone on any part of the vertical wall of a silo

1.5.30
pipe flow
a flow pattern in which the particulate solid in a vertical or nearly vertical channel above the outlet is in motion, but is surrounded by stationary solid (see Figures 3.1b and 3.2). Flow may occur against the silo wall if the outlet is eccentric (see Figures 3.2c and d) or if specific factors cause the channel location to move from above the outlet (see Figure 3.4d)

1.5.31
plane flow
a flow profile in a rectangular or a square cross-section silo with a slot outlet. The slot is parallel with two of the silo walls and its length is equal to the length of these walls

1.5.32
powder
for the purposes of this standard, a solid whose mean particle size is less than 0,05 mm is classed as a powder

1.5.33
pressure
force per unit area normal to a wall of the silo

1.5.34
retaining silo
a silo whose bottom is flat and where $h_c/d_c \leq 0{,}4$

1.5.35
shallow hopper
a hopper in which the full value of wall friction is not mobilized after filling the silo

1.5.36
silo
containment structure used to store particulate solids (i.e. bunker, bin or silo)

1.5.37
slender silo
a silo where $h_c/d_c \geq 2{,}0$ or that meets the additional conditions defined in 3.3

1.5.38
slenderness
the aspect ratio h_c/d_c of the silo vertical section

1.5.39
squat silo
a silo where $0{,}4 < h_c/d_c \leq 1{,}0$ or that meets the additional conditions defined in 3.3. Where $h_c/d_c \leq 0{,}4$, the silo is squat if there is a hopper, but a retaining silo if the bottom is flat

1.5.40
steep hopper
a hopper in which the full value of wall friction is mobilized after filling the silo

1.5.41
stress in the stored solid
force per unit area within the stored solid

1.5.42
tank
containment structure used to store liquids

1.5.43
thick-walled silo
a silo with a characteristic dimension to wall thickness ratio less than $d_c/t = 200$

1.5.44
thin-walled circular silo
a circular silo with a diameter to wall thickness ratio greater than $d_c/t = 200$

1.5.45
traction
force per unit area parallel to the wall of the silo (vertical or inclined)

1.5.46
transition
the intersection of the hopper and the vertical wall

1.5.47
vertical walled segment
the part of a silo or a tank with vertical walls

1.5.48
wedge hopper
a hopper in which the sloping sides converge only in one plane (with vertical ends) intended to produce plane flow in the stored solids

1.6 Symbols used in Part 4 of Eurocode 1

A list of elementary symbols is provided in EN 1990. The following additional symbols are specific to this part. The symbols used are based on ISO 3898: 1997.

1.6.1 Roman upper case letters

A plan cross-sectional area of vertical walled segment

A_c plan cross-sectional area of flow channel during eccentric discharge

B depth parameter for eccentrically filled squat silos

C load magnifying factor

C_o discharge factor (load magnifying factor) for the solid

C_{op} patch load solid reference factor (load magnifying factor) for the stored solid

C_b bottom load magnifying factor