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Part 4: Silos and tanks

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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 - Einwirkungen auf Tragwerke - Teil 4:
Einwirkungen auf Silos und Flüssigkeitsbehälter

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 250.

If this draft becomes a European Standard, 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.

This draft European Standard was established by CEN 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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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

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

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European foreword

This document (prEN 1991-4:2024) 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 and has been assigned responsibility for structural and geotechnical design matters by CEN.

This document is currently submitted to the CEN Enquiry.

This document will supersede EN 1991-4:2006 and AC:2012.

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.

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 the 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 the EN 1991 series

(1) The EN 1991 series specifies actions for the structural and geotechnical design of buildings, bridges and other civil engineering works, or parts thereof, including temporary structures, in conjunction with EN 1990 and the other Eurocodes.

(2) The EN 1991 series does not cover the specific requirements of actions for seismic regions. Provisions related to such requirements are given in the EN 1998 series, which complement and are consistent with the EN 1991 series.

(3) The EN 1991 series is also applicable to existing structures for:

- structural assessment,
- strengthening or repair,
- change of use.

NOTE In these cases additional or amended provisions can be necessary.

(4) The EN 1991 series is also applicable for the design of structures where materials or actions outside the scope of the other Eurocodes are involved.

NOTE In this case additional or amended provisions can be necessary.

0.3 Introduction to EN 1991-4

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

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 prEN 1991-4

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 prEN 1991-4 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 1991-4 through notes to the following clauses:

1.1(4)	4.1(2)	5.5.16(2)	5.7(7)
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National choice is allowed in EN 1991-4 on the application of the following informative annexes:

Annex A	Annex B	Annex F	Annex G
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The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of EN 1991-4

(1) EN 1991-4 provides guidance for calculating actions for the structural design of silos and tanks.

NOTE 1 Silos are used for the storage of particulate solids: tanks are used for the storage of liquids.

NOTE 2 For limitations on rules for silos given in this document, see 1.3.

NOTE 3 For limitations on rules for tanks given in this document, see 1.4.

(2) EN 1991-4 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) but substantially affected by them.

NOTE Liquid loads on tanks are very precisely defined. Many loads on silos are not known with great precision. This standard provides guidance for many practical situations for which very limited certain knowledge is available, and the information is derived from the limited experimental and analytical information available, coupled with conclusions drawn from failure investigations. The information is not based on a sound statistical treatment of experimental data.

(3) EN 1991-4 is intended for use with concrete, steel, aluminium, timber and FRP storage structures.

NOTE FRP is the standard acronym for fibre reinforced polymer materials.

(4) EN 1991-4 may be used for the structural assessment of existing construction, in developing the design of repairs and alterations or for assessing changes of use.

NOTE Where the structural appraisal of an existing structure is being considered, reference can be made to the National Annex and to the client concerning the relevance of the current standard.

1.2 Assumptions

(1) The assumptions of EN 1990 apply.

(2) EN 1991-4 is intended to be used in conjunction with EN 1990, with the other parts of EN 1991, EN 1992, EN 1993, EN 1995, EN 1997, EN 1998 and EN 1999 where relevant to the design of silos and tanks.

1.3 Limitations on silos

1.3.1 Geometrical limitations

(1) The following geometrical limitations apply to the design rules for silos covered by this document:

- the silo here defined is either an isolated structure or can be part of a battery of silos. For a silo battery, the term silo is used throughout this standard to refer to a single cell within the battery;
- the silo planform cross-section shapes are limited to those shown in Figure 1.1c.

NOTE 1 Minor variations to these shapes can be accepted provided the structural consequences of the resulting changes in pressure are expected to be considered. Further information concerning planform cross-section geometries is given in 7;

NOTE 2 Further information concerning planform cross-section geometries is given in Clause 7.

- the relevant overall height of the silo h_b (Figure 1.1a) is measured from the level of the equivalent surface of the stored solid (see 3.2.17) when the silo is filled to its maximum capacity, down to the apex of the cone of the hopper or to the flat base where there is no hopper;

NOTE For the evaluation of h_o to calculate h_b , see (2).

- the effective diameter d_c of the silo should be determined as indicated in Figure 1.1c;
- the following dimensional limitations on the overall height h_b and aspect ratio h_b/d_c apply (see Figure 1.1):

$$h_b/d_c < 10 \quad (1.1)$$

$$h_b < 100 \text{ m} \quad (1.2)$$

$$d_c < 60 \text{ m} \quad (1.3)$$

- the structural transition lies in a single horizontal plane (see Figure 1.1a);
- the relevant cylindrical section height of the silo h_c (Figure 1.1a) should be measured from the level of the equivalent surface of the stored solid (see 3.2.17) when the silo is filled to its maximum capacity, down to the structural transition (see Figure 1.1a) or to the flat base where there is no hopper;

(2) For a symmetrically filled circular silo of diameter d_c , h_o should be determined as:

$$h_o = \frac{d_c}{6} \tan \phi_r \quad (1.4)$$

and for a symmetrically filled rectangular silo of characteristic dimension d_c , h_o should be determined as:

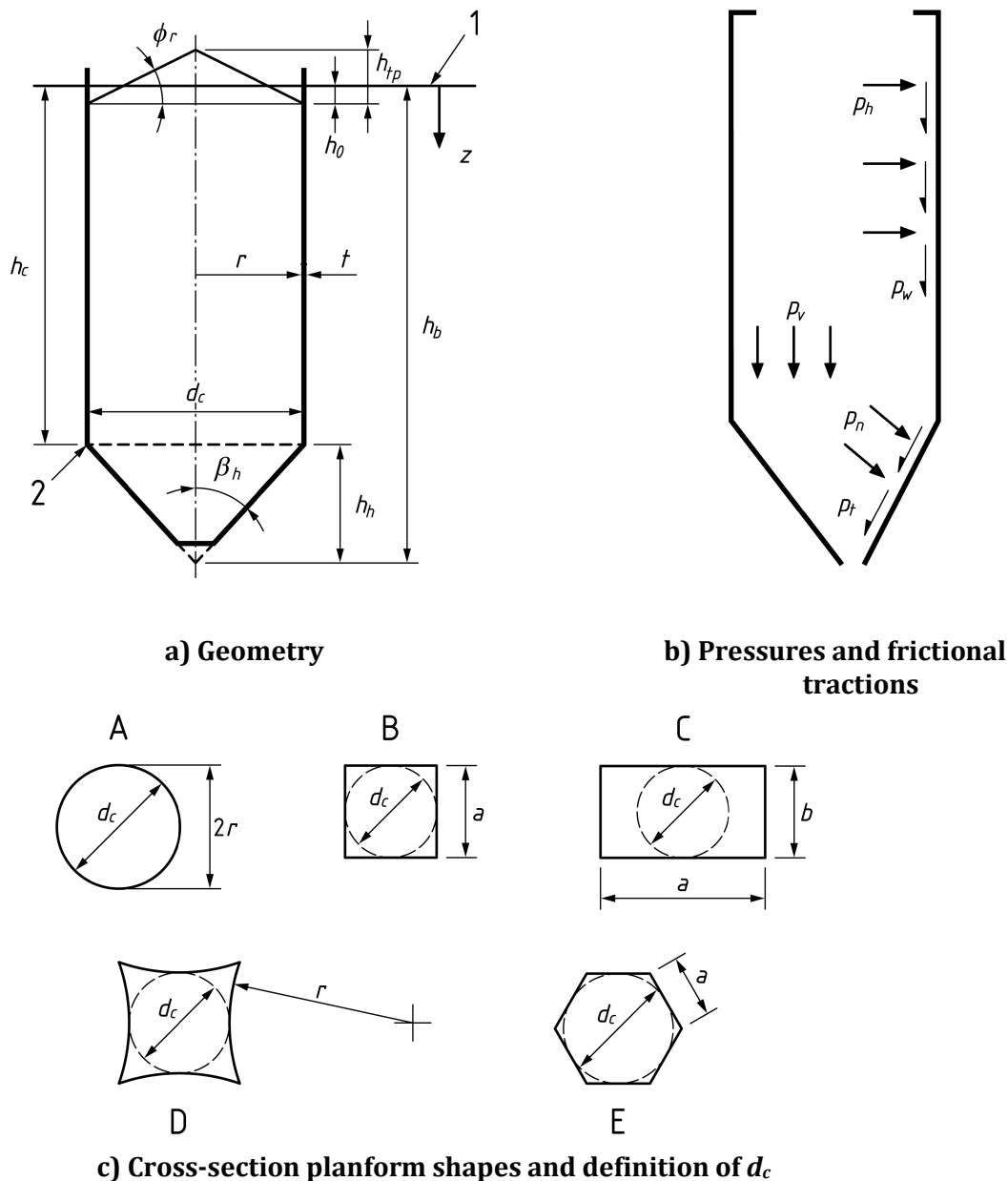
$$h_o = \frac{d_c}{4} \tan \phi_r \quad (1.5)$$

where:

ϕ_r is the angle of repose of the solid (see Table C.1).

NOTE For solids that can become fluidised on filling, the value of ϕ_r can also be zero.

(3) The value of h_o for a powder may normally be taken as $h_o = 0$ because the solid is naturally aerated on deposition. Silo design for storing powders should allow for higher filling levels arising from this effect.



- Key**
- 1 Equivalent surface
 - 2 Transition
 - A Circular
 - B Square
 - C Rectangular
 - D Interstitial
 - E Hexagonal

Figure 1.1 — Silo forms showing dimensions and pressure notation

- (4) Only hoppers that are conical (i.e. axisymmetric), rectangular pyramidal, wedge-shaped (i.e. with vertical end walls) or oblique are covered by this standard. Other hopper shapes and hoppers with internal structures require special considerations.
- (5) Silos with an oblique conical hopper used to achieve an eccentric outlet are covered by this standard.

(6) Silos with an oblique hopper are covered, but generally silos with a systematically non-symmetric geometry are not specifically covered by this standard. These situations include a chisel hopper (i.e. a wedge hopper beneath a circular cylinder), a diamond-back hopper and a transition hopper that transforms a rectangular into a circular cross-section.

NOTE A transition hopper for a circular silo transforms the circular cross-section into a rectangular shape, or for a rectangular silo it transforms a rectangular into a circular cross-section from the transition to the outlet. These forms are not explicitly treated in this standard, but the provisions for circular hoppers are believed to be suitable for structural design purposes.

- a cylindrical silo does not contain internal structures other than an inverted cone at the base.
- the loads induced by discharge arms, stationary and rotating feeders, and similar equipment are outside the scope of this standard. Information concerning such loads should be obtained from the manufacturers of the equipment.

1.3.2 Limitations on the stored solids

(1) The following limitations on the stored solids apply to the design rules for silos contained in this document:

- each silo is designed for a defined range of particulate solids properties;
- the stored solid is either naturally free-flowing or can be guaranteed to flow freely within the silo container as designed;
- for stored solids in Flow Group C (see Annexes C and D), special provisions can be necessary (see 5.4);
- stored solids in Flow Group D (see Annexes C and D) are excluded, except where they are stored in silos unloaded from the top (see Figure 5.3a and 7.2.2);
- each silo is designed for a defined mode of operation;
- the maximum particle dimension in the stored solid is not greater than $0,03d_c$ (see Figure 1.1c).

NOTE 1 The relevance of the possible range of the particulate solids parameters to the design of a specific silo can be agreed by the relevant parties. Where any uncertainty exists, the client can obtain specialist advice from an appropriate testing laboratory (see also Annex D).

NOTE 2 Where large particles are stored, the outlet dimension is required to be sufficiently large to ensure that mechanical interlocking does not occur.

NOTE 3 Where stored particles are large compared to the silo characteristic dimension d_c , significant problems can occur due to mechanical interlocking that this standard does not address.

NOTE 4 Where particles are large compared to the silo wall thickness, a single particle can apply a large local force on the wall. This aspect is outside the scope of this standard.

(2) The phenomena of solid-induced vibrations, oscillations and shocks (quaking, honking, banging, etc.) are outside the scope of this standard. Silos that are used to store particulate solids that can induce these effects can require special load assessments or special design considerations beyond the scope of this standard.

1.3.3 Limitations on filling and discharge arrangements

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

- filling and/or discharge involves only negligible inertia effects and impact loads;
- where discharge devices are used (for example feeders or anti-dynamic tubes), the solids flow should be known to be smooth and reliable.

NOTE 1 This standard includes the filling pressures in square or rectangular silos that contain internal structural ties between the vertical walls.

NOTE 2 Extreme rates of filling and discharge can give rise to dynamic loads that are not considered in this document (see also (15)).

(2) It can be necessary to use discharge aids to achieve free flow (see 3.2.25 and Annex D). This standard does not provide rules for the following possible features of a silo: discharge feeders, anti-dynamic tubes, chinese hats, cross-beams and structural elements inserted into the solids flow domain.

(3) Variations that can occur in the discharge of solids arising from fluctuations of particulate solid properties caused by changes of humidity and temperature inside the silo and the wall surface leading to disturbances of the flow pattern are outside the scope of this standard.

(4) The loads induced by discharge arms, stationary and rotating feeders, and similar equipment are outside the scope of this standard. Information concerning such loads should be obtained from the manufacturers of the equipment.

NOTE Special conditions can lead to moisture deposition if the dew point is reached at the wall surface. Wet surfaces can cause particulate solid to stick to the wall, leading to flow problems and higher local pressures or non-symmetric load patterns that are not considered in the design situations of this standard and are outside the scope of this standard.

(5) The silo loads defined in this standard are premised on the assumptions of isotropic or orthotropic shell theory, with membrane and bending resultants in the silo wall. Concrete silos are generally considered to be thick-walled silos, whilst metal and FRP silos are generally to be considered to be thin-walled silos. In other structural forms, such as wooden stave silos, the load conditions should be carefully considered, with special attention to the consequences of non-symmetrical pressures (e.g. the proxy load rules).

(6) The functional design of silos is outside the scope of this standard, but consideration should be given to the blockage of the outlet if particle sizes exceed $d_o/8$, where d_o is the characteristic dimension of the outlet.

(7) Loads that arise from silo quaking, shocks, honking, pounding and silo music are not defined in this standard. However, the rules of this standard may be used for silos that can be susceptible to these phenomena, but this specific aspect of design is classified as AAC4.

NOTE These phenomena are not well understood but are believed to be a consequence of the pattern of solids flow. The use of this standard does not guarantee that these phenomena will not occur, or that the designed structure will be adequate to resist the forces they can induce.

(8) The design of silos for the storage of silage and haylage is outside the scope of this standard.

(9) Silos in AAC4 or Consequence Class 4 may be designed according to the rules of this standard, but further information can be required to guarantee the safety of the design.

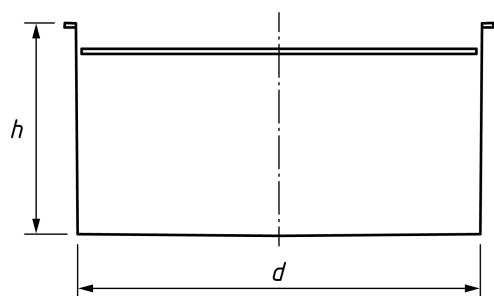
(10) The actions on the silo structure from feeders and gates are not specified in this standard. These include those from unattached feeders that can transfer loads to the silo structure through the stored solid.

(11) The actions on the catwalks, ladders, gantries, feeders, conveyors and other structures connected to a silo are outside the scope of this standard.

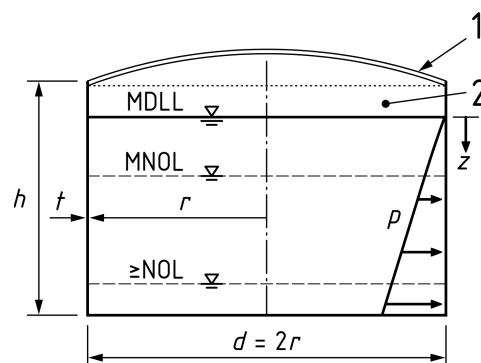
1.4 Limitations on tanks

(1) The rules in this standard apply to on-ground or elevated (pedestal and/or column or girder supported) tanks (Figure 1.2).

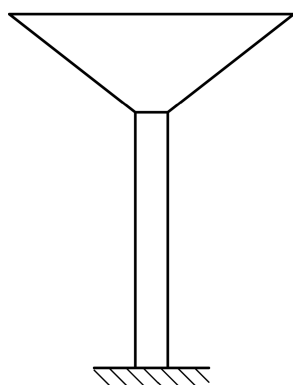
(2) The rules for tanks apply only to tanks storing liquids with only small vapour pressures above the surface. The upper limit for the pressure in the vapour space above the liquid in a tank is 500 mbarg (= 50 kPa).



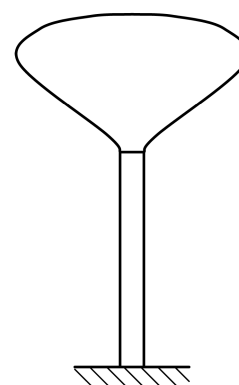
a) Cylindrical on-ground tank with floating roof



b) Cylindrical on-ground tank with dome roof



c) Pedestal tank with conical form



d) Pedestal tank with tori-spherical form

Key

- 1 Roof
- 2 Vapour space

Figure 1.2 — Tank forms showing dimensions and pressure notation

NOTE For simplicity and clarity in Figure 1.2b, only the liquid level MDLL has been identified with its dimensional location h_L with its corresponding depth coordinate x_L . The other defined liquid levels, MNOL and min. NOL, are marked to indicate their locations.

(3) The actions on the roofs of tanks defined in EN 1991-1-1, EN 1991-1-3 to EN 1991-1-7 and EN 1991-3 should be considered.

(4) The actions on the catwalks, ladders, gantries, pipework and other structures connected to a tank are outside the scope of this standard.

(5) This standard does not cover tanks used to store liquids whose vapours are susceptible to explosion (CC4).

NOTE 1 Loads exerted on structures near a tank as a result of an explosion within it can be evaluated according to EN 1991-1-7.

NOTE 2 The National Annex can give guidance on the pressure exerted on structures near the tank as a result of an explosion within it.

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. in 'should' clauses), permissions (i.e. through 'may' clauses), possibilities ('can' clauses), and in notes.

EN 1990:2023,¹ *Eurocode — Basis of structural and geotechnical design*

3 Terms, definitions and symbols

3.1 General

For the purposes of this document, the terms and definitions given in EN 1990:2023 and the following apply.

3.2 Terms and definitions

3.2.1

Action Assessment Class

AAC

classification of a silo or tank to address the appropriate level of complexity in the different forms of action to be addressed, including evaluation of the magnitude of the action to achieve a similar level of reliability in relation to the size of a silo, its stored granular solid and the mode of operation of the silo

3.2.2

aerated silo bottom

silo base in which air slides or air injection is used to activate flow in the bottom of the silo

3.2.3

aspect ratio for slenderness assessment (silos)

ratio of the height h_c of the vertical solid storage part of a silo (from the top of the solid pile to the structural transition or the base of a flat-bottomed silo) to the characteristic dimension d_c of the plan form

3.2.4

aspect ratio (tanks)

ratio of overall height h_T of the liquid storage part of a tank (from the highest liquid level to the bottom of the tank) to the diameter d of the plan form

¹ As impacted by EN 1990:2023/prA1:2024

3.2.5**characteristic dimension of inside of silo cross-section**

diameter of the largest inscribed circle within a silo cross-section

3.2.6**circular silo**

silo whose plan cross-section is circular

3.2.7**cohesion**

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

3.2.8**conical hopper**

hopper in the form of a right circular cone, in which the sloping sides converge towards a single point lying on the central vertical axis intended to produce axisymmetric flow in the stored solid in a silo with a circular planform

3.2.9**consequence class**

CC

classification of a silo or tank to address the consequences of structural failure

3.2.10**diameter**

diameter of a silo or tank, the middle surface diameter of a cylindrical shell structure, or for a silo with non-circular planform, the effective diameter of the inscribed circle

3.2.11**discharge load**

pressures acting on the walls of a silo during the discharge process, assuming that the silo is still in its full condition, but that the flow pattern of the discharge has been fully developed or during simultaneous filling and discharge

3.2.12**discharge process**

pattern of flow of solids induced by the opening of an outlet, leading to granular solids flow in some or all of the silo, and continuing with potentially different flow patterns until the silo is empty

3.2.13**eccentric discharge**

flow pattern in the stored solid arising from moving solid being unsymmetrically distributed relative to the vertical centreline of the silo, normally arising from an eccentrically located outlet (see Figures 5.7b and c, 5.8c and d, and 5.9c), but also caused by other unsymmetrical phenomena

3.2.14**eccentric filling**

condition in which, at any stage of the filling process, the top of the heap at the top of the stored solids is not located on the vertical centreline of the silo

3.2.15**effective transition**

level at which the boundary between the flowing and stationary solid strikes the silo wall in a silo in which the solid flows in a mixed flow mode

3.2.16

effective elastic modulus

local value, at a given mean vertical stress level, of the rate of change of mean vertical stress with local vertical strain in a compressed granular solid under uniaxial strain (tangent modulus of elasticity)

3.2.17

equivalent surface

level surface giving the same volume of stored solid as the actual surface

3.2.18

expanded flow hopper

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 to cause funnel flow thereby assuring reliable discharge whilst providing a larger silo volume with a lower hopper height

3.2.19

filling load

pressures acting on the walls of a silo during the filling process and during storage in the full condition

3.2.20

filling process

placement of solids in a silo by gravity fall from a chute or distributor above the highest surface corresponding to the full condition, leading to a packing structure (fabric) in the solids which affects the bulk unit weight, the void ratio, the particle orientations and anisotropy, and the inhomogeneity between different zones, which can all affect the pattern of flow of solids during discharge and the pressures exerted on the silo walls

3.2.21

flat bottom

internal base of a silo when it has an inclination to the horizontal less than 20° , or for a tank less than 5°

3.2.22

Flow Group

FG

categorisation of a particulate solid in relation to its ease of free flow when a discharge opening is in operation

3.2.23

flow pattern

form of moving solid in a silo when solids flow is well established and the silo remains close to the full condition

3.2.24

fluidized solid

state of a stored fine particulate solid when its bulk contains a high proportion of interstitial air, with a pressure gradient that partially or fully supports the weight of the particles, as a consequence of air being introduced either by aeration or by the filling process

Note 1 to entry: A solid is said to be partially fluidized when only part of the weight of particles is supported by the interstitial air pressure gradient.

3.2.25**free-flowing granular solid**

granular solid whose flowing behaviour under gravity is not significantly affected by cohesion or angularity of the particles

Note 1 to entry: A solid can be made to flow freely by the use of flow aids or by a mass flow design, see also prEN 1991-4:2024, Annex D.

3.2.26**full condition (silos)**

state of solid in a silo when the top surface of the stored solid is at the highest position considered possible under operating conditions during the design lifetime of the structure

Note 1 to entry: This is the assumed design condition for the silo when considering both filling and discharge loads.

3.2.27**full condition (tanks)**

state of liquid in a tank when the liquid surface is at the highest position considered possible under normal operating conditions during the design lifetime of the structure

3.2.28**Silo Fundamental Load Case**

SFLC

simple essential symmetrical loading conditions required for all silos

3.2.29**funnel flow**

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

Note 1 to entry: The flow channel can intersect the vertical walled segment (mixed flow) or extend to the surface of the stored solid (pipe flow).

3.2.30**granular solid**

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

3.2.31**high filling velocity**

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

3.2.32**homogenizing fluidized silo**

silo in which the particulate solid is fluidized to assist blending

3.2.33**hopper**

silo bottom with inclined walls

3.2.34

hopper pressure ratio

F

ratio of the local 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

3.2.35

intermediate slenderness silo

silo where $1,0 \leq h_c/d_c < 2,0$

3.2.36

internal pipe flow

pipe flow pattern in which the flow channel boundary extends to the surface of the stored solid without contact with the wall

3.2.37

inverted cone

conical internal structure at the base of a silo with its apex upwards, used as part of the discharge system

3.2.38

lateral pressure ratio

K

ratio of the mean horizontal pressure p_h acting on the vertical wall of a silo at a specific level to the mean vertical stress p_v in the solid at the same level

3.2.39

low cohesion

for a particulate solid sample, low cohesion if the cohesion c is less than 4 % of the pre-consolidation stress σ_r

3.2.40

mass flow

flow pattern in which all the stored particles are simultaneously in motion during discharge

3.2.41

maximum design liquid level

MDLL

highest liquid level in a tank to be used as an accidental design situation

Note 1 to entry: This is higher than the maximum normal operating level.

3.2.42

maximum normal operating liquid level

MNOL

highest liquid level in a tank under normal operating conditions

Note 1 to entry: This is lower than the maximum design liquid level.

3.2.43

mixed flow

funnel flow pattern in which the flow channel intersects the vertical wall of the silo at a point below the highest wall to solid contact (i.e. the surface at the wall)

3.2.44**modulus contiguity coefficient** **χ_L and χ_U**

coefficient of the component of the effective elastic modulus that is linearly related to the mean vertical stress (subscript L for under increasing load, subscript U for under decreasing load)

3.2.45**non-circular silo**

silo whose plan cross-section is in any shape that is not circular

3.2.46**oblique conical hopper**

hopper at the base of a circular planform silo, arranged with its central axis inclined to the vertical to achieve an outlet that lies eccentric to the vertical axis of the cylinder, thus permitting the stored solid in the silo to be extracted from a position that is eccentric to the main vertical axis (its planform is strictly an elliptical cone)

3.2.47**overall aspect ratio (silos)**

ratio of overall height h_b of the solid storage part of a silo (from the top of the solid pile to the bottom of the hopper) to the characteristic dimension d_c of the plan form

3.2.48**particulate solid**

solid in the form of many discrete and independent particles

Note 1 to entry: In the literature often called “bulk solid” or “granular solid”.

3.2.49**proxy load**

specially defined load that induces suitable stress resultants in the silo wall that correspond to the important effects of unsymmetrical real load patterns that are much more complicated

3.2.50**pipe flow**

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 so that solids flow is normally internal to the solid but can occur against the silo wall if the outlet is eccentric or if specific factors cause the channel location to move from above the outlet

3.2.51**plane flow**

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

3.2.52**powder**

particulate solid whose mean particle dimension is less than 0,05 mm as used in this standard

3.2.53**pressure**

force per unit area acting normal to any structural surface (e.g. a silo or tank wall, roof, bottom, etc.)

3.2.54

process silo

silo that is regularly filled and partially or fully discharged throughout each year (more than 50 times per year)

Note 1 to entry: The value of 50 is intended to indicate a regularity of filling and emptying.

3.2.55

rectangular silo with flexible walls

square or rectangular planform silo constructed with plates whose horizontal flexural stiffness is comparable with the stiffness of the stored solid

3.2.56

rectangular silo with internal ties

square or rectangular silo with ties between its sides to reduce the bending moments in the walls

3.2.57

retaining silo

silo whose bottom is flat and where $h_c/d_c \leq 0,4$ ($h_b = h_c$ for retaining silos)

3.2.58

shallow hopper

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

3.2.59

silo

single containment structure used to store particulate solids (also known as a bunker, bin or silo cell)

Note 1 to entry: This term also refers to a single cell in a silo battery.

3.2.60

silo battery

group of containment structures closely linked, permitting many different types of similar solids to be stored separately (note that in some languages the term “silo” is also used to mean a silo battery)

3.2.61

slender silo

silo where $2,0 \leq h_c/d_c < 4,0$

3.2.62

slenderness

cylindrical aspect ratio h_c/d_c for a silo (see Figure 3.1) or h_T/d of a tank

3.2.63

Silo Special Load Case

SSLC

load case separately defined from the remainder of the standard, in which more demanding load conditions occur under solids flow that require special loading definitions

3.2.64

squat silo

silo where $0,4 \leq h_c/d_c < 1,0$. Where $h_c/d_c < 0,4$, the silo is squat if there is a hopper, but a retaining silo if the bottom is flat

3.2.65**steep hopper**

hopper in which the full value of wall friction is mobilized after filling the silo (i.e. the solid slides on the hopper wall during its settlement after filling)

3.2.66**storage silo**

silo with an inflow and/or partial discharge less than 50 times per year

3.2.67**stress in the stored solid**

force per unit area within the stored solid

3.2.68**structural transition**

position in a silo structure where the hopper wall meets the vertical wall

3.2.69**tank**

containment structure used to store liquids

3.2.70**tank load**

actions from stored liquid, gas, vapour or air pressure above the liquid surface or from the temperature of the liquid, gas, vapour or air

3.2.71**thick-walled circular silo**

silo with a ratio of diameter to wall thickness less than or equal to $d_c/t = 200$

Note 1 to entry: For timber structures, see 1.2(17).

3.2.72**thin-walled circular silo**

circular silo with a ratio of diameter to wall thickness greater than $d_c/t = 200$

Note 1 to entry: Where the silo wall is corrugated or double skinned, the wall thickness is taken as the thickness of the metal sheet.

Note 2 to entry: Tanks are not distinguished in EN 1991-4 according to whether the wall is thick or thin.

3.2.73**top pile centroidal height**

h_o

height of the centroid of the top pile of solids above the highest point of solids contact with the wall

3.2.74**traction**

force per unit area acting on a silo wall surface and parallel to the wall (vertical or inclined) arising from shear stresses in the stored solid

3.2.75**vapour space in a tank**

space above the surface of the stored liquid and below the roof in a tank

3.2.76

vertical walled segment

vertical wall part of a silo or tank

3.2.77

very slender silo

silo with aspect ratio h_c/d_c greater than or equal to 4,0

3.2.78

Wall Surface Category

classification of the friction properties of the silo or hopper wall relative to the specific stored solid

3.2.79

wedge hopper

hopper in which the sloping sides converge only in one plane and the hopper has vertical ends, intended to produce plane flow in the stored solid

3.2.80

well-known solid

particulate solid that has been widely tested and for which many silos have been successfully constructed so that reliable values of the solid properties for silo design are widely accepted

Note 1 to entry: The solids that this standard recognizes as well-known are marked W in Table C.2.

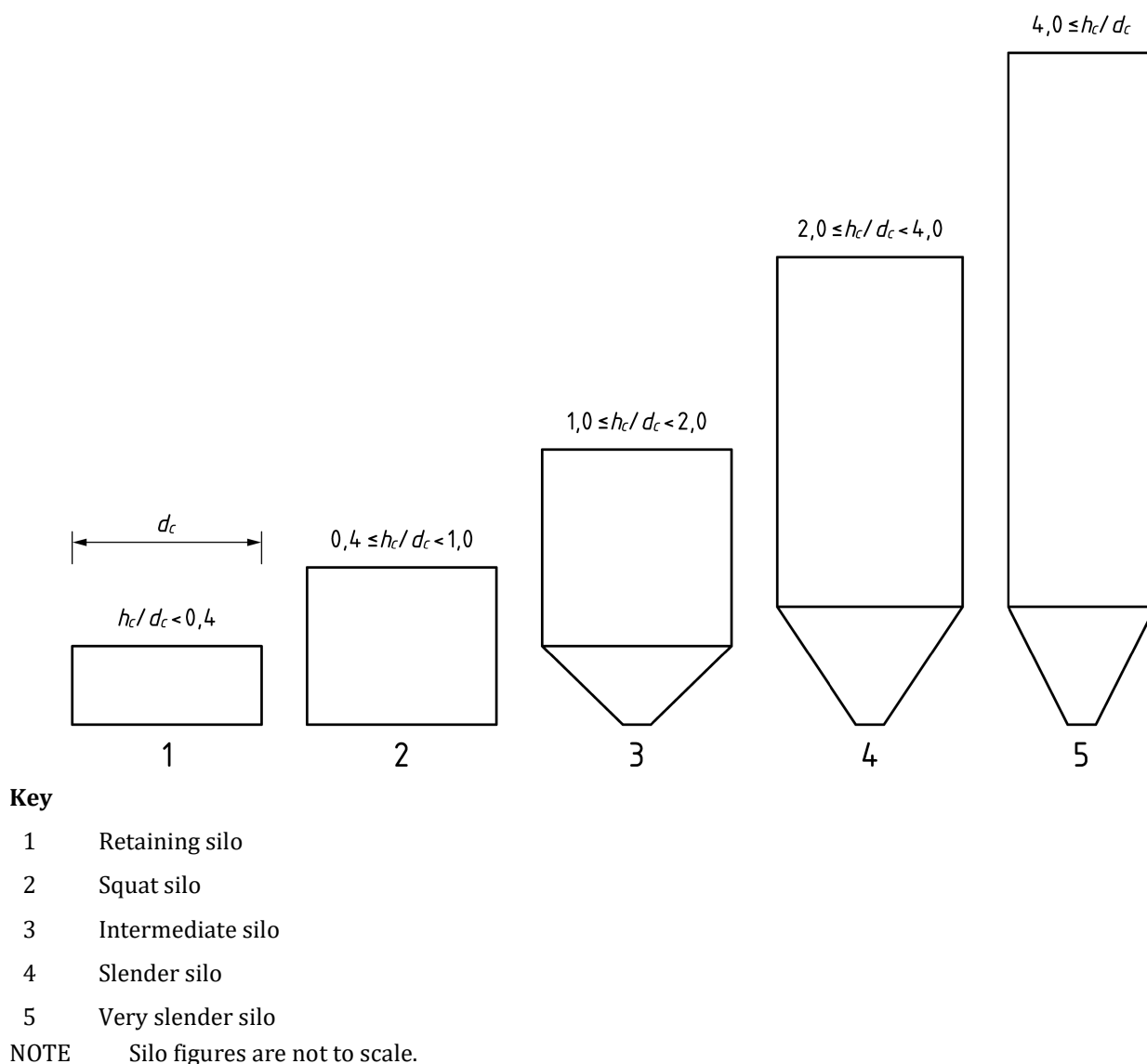


Figure 3.1 — Aspect ratio definitions

3.3 Symbols and abbreviations

For the purposes of this document, the symbols in EN 1990:2023 and the following apply. The symbols used are based on ISO 3898.

3.3.1 Roman upper-case letters

A	plan cross-sectional area of vertical walled segment
A_c	plan cross-sectional area of the flow channel during eccentric discharge
A_s	plan cross-sectional area of the stationary solid during eccentric discharge
C_{ohf}	oblique hopper filling pressure factor
C_{ohe}	oblique hopper discharge pressure factor
C_p	proxy load factor
C_T	load multiplier for temperature differentials

E_{sL}	effective loading elastic modulus of a stored solid at relevant stress level
E_{sLo}	the base loading effective modulus of a stored solid
E_{sU}	effective unloading elastic modulus of a stored solid at relevant stress level
E_{sUo}	the base unloading effective modulus of a stored solid
E_w	elastic modulus of silo wall
F	ratio of normal pressure on hopper wall to mean vertical stress in the solid
F_e	hopper normal pressure ratio during discharge
F_f	hopper normal pressure ratio after filling
G	ratio of radius of flow channel to radius of circular silo
K	characteristic value of lateral pressure ratio (ratio of mean horizontal pressure to mean vertical stress in the solid)
K_m	mean value of lateral pressure ratio
K_o	value of K measured for zero horizontal strain, under horizontal and vertical principal stresses
S	hopper geometry factor (=2 for conical, = 1 for wedge)
U	internal perimeter of the plan cross-section of the vertical walled segment
U_{sc}	internal perimeter of flow channel to static solid contact under eccentric discharge
U_{wc}	internal perimeter of flow channel wall contact under eccentric discharge
U_{ws}	internal perimeter of stationary solid wall contact under eccentric discharge
Y	depth variation function
Y_j	Janssen pressure depth variation function for slender silos
Y_R	squat and intermediate slenderness silo pressure depth variation function

3.3.2 Roman lower-case letters

a	side length of a square or hexagonal silo or long side of a rectangular silo
a	property modification coefficient to give upper and lower characteristic values from mean values, see the following definitions:
a_K	modification coefficient for lateral pressure ratio
a_γ	modification coefficient for bulk unit weight of a particulate solid
a_ϕ	modification coefficient for internal friction angle
a_μ	modification coefficient for wall friction coefficient
b	short side length of a rectangular silo
c	cohesion of the solid
d	diameter of a cylindrical tank
d_c	characteristic horizontal dimension of the inside of a silo cross-section
d_o	characteristic dimension of the outlet
e_e	global eccentricity for the purposes of a discharge calculation, defined as the larger of e_f and e_o
e_c	eccentricity of the centre of the flow channel in highly eccentric flow
e_f	maximum eccentricity associated with the silo filling process

e_o	eccentricity of the centre of the outlet
e_t	eccentricity of the centre of the top surface pile
h_b	overall height of a silo from the hopper apex to the equivalent surface
h_c	height of vertical-walled (cylindrical) segment of a silo from the transition to the equivalent surface
h_h	height of hopper in a silo from the apex to the transition
h_L	height of the liquid surface in a tank when filled to maximum design liquid level (MDLL)
h_{MNOL}	height above the base of liquid surface in a tank at the maximum normal operating level (MNOL)
h_o	top pile centroidal height in a silo: depth below the equivalent surface of the base of the top pile (lowest point on the wall that is not in contact with the stored solid)
h_{test}	liquid level above the base in a tank under hydrostatic test conditions
h_{tp}	total height of the top pile of solid (vertical distance from lowest point on the wall that is not in contact with the stored solid to the highest stored particle)
h_T	overall height of the vertical wall of a tank from the base to the eaves or roof junction
h_{TL}	lowest height above the hopper apex of a possible location for the effective transition under mixed flow
n	power in hopper pressure distribution
n_{zSk}	characteristic value of vertical stress resultant per unit perimeter in the vertical walled segment
p	pressure (normal stress applied by the solid against a structural surface)
p_h	horizontal pressure due to stored particulate solid
$p_{h,b}$	characteristic total horizontal pressure in the band load
p_{hae}	horizontal pressure in static solid adjacent to the flow channel during eccentric discharge
p_{hce}	horizontal pressure in flow channel during eccentric discharge
p_{hco}	asymptotic horizontal pressure at great depth in flow channel during eccentric discharge
p_{he}	horizontal pressure during discharge
p_{hf}	horizontal pressure after filling and during storage
p_{hfb}	horizontal pressure after filling at the base of the vertical walled segment
p_{ho}	asymptotic horizontal pressure at great depth due to stored particulate solid
p_{hse}	horizontal pressure in static solid distant from the flow channel during eccentric discharge
p_{hT}	increase in horizontal pressure due to a temperature differential for squat and intermediate slenderness silos
p_{hTs}	increase in horizontal pressure due to a temperature differential for slender silos
p_n	pressure normal to hopper wall due to stored particulate solid
p_{nc}	pressure normal to the internal inverted cone
p_{ne}	pressure normal to hopper wall during discharge
$p_{ne,sym}$	pressure during discharge normal to hopper wall in a symmetrical hopper that is equivalent to an oblique hopper
$p_{ne\theta}$	pressure during discharge normal to oblique hopper wall at circumferential coordinate θ

p_{nf}	pressure normal to hopper wall after filling and during storage
$p_{nf,sym}$	pressure after filling normal to hopper wall in a symmetrical hopper that is equivalent to an oblique hopper
$p_{nf\theta}$	pressure after filling normal to oblique hopper wall at circumferential coordinate θ
p_t	hopper frictional traction
p_{te}	hopper frictional traction during discharge
$p_{te\theta}$	frictional traction during discharge on oblique hopper wall at circumferential coordinate θ
p_{tf}	hopper frictional traction after filling and during storage
$p_{tf\theta}$	frictional traction after filling on oblique hopper wall at circumferential coordinate θ
p_v	vertical stress in stored solid
p_{vb}	vertical pressure acting on the base of a flat-bottom silo
p_{vf}	vertical stress in stored solid after filling and during storage
p_{vft}	vertical stress in the stored solid at the transition after filling (base of the vertical walled segment)
p_{vsq}	vertical pressure acting on the flat bottom of a squat or intermediate slenderness silo
p_w	wall frictional traction on the vertical wall (frictional shear force per unit area) of a silo
p_{wc}	wall frictional traction on the internal inverted cone
p_{wae}	wall frictional traction in static solid adjacent to the flow channel during eccentric discharge
p_{wce}	wall frictional traction in flow channel during eccentric discharge
p_{we}	wall frictional traction during discharge
p_{wf}	wall frictional traction after filling and during storage
p_{wse}	wall frictional traction in static solid distant from the flow channel during eccentric discharge
r	equivalent radius of silo ($r = 0,5d_c$)
r_c	radius of an eccentric flow channel in stored solid
r_T	radius of the inside surface of a tank vertical wall
s	dimension of the zone affected by the proxy load ($s = \pi d_c/16 \cong 0,2d_c$)
t	silo or tank wall thickness
x	vertical coordinate in hopper with origin at cone or pyramidal apex
x_L	global vertical coordinate measured down from the liquid surface level h_L in a tank
z	depth below the equivalent surface of the solid in the full condition
z_o	Janssen characteristic depth
z_{oc}	Janssen characteristic depth for flow channel under eccentric discharge
z_s	depth below the highest solid wall contact
z_T	depth of the effective transition under mixed flow
$z_{T,max}$	depth of the lowest possible position of the effective transition under mixed flow
z_V	depth measure used for vertical stress evaluation in squat silos

3.3.3 Greek upper-case letters

ΔT	difference between temperature of the stored solid and the silo wall
Δv	increment of vertical displacement measured during materials testing
$\Delta \sigma$	increment of stress applied to a cell during materials testing

3.3.4 Greek lower-case letters

α	horizontal pressure distribution factor for rectangular thin-walled silos
α_w	thermal expansion coefficient for silo wall
β_c	inclination to the vertical of an inverted cone within a silo
β_h	angle of inclination of hopper wall measured from the vertical, or the steepest slope on a square or rectangular pyramidal hopper
$\beta_{ho,eq}$	angle of inclination for an oblique hopper of the equivalent symmetrical hopper
$\beta_{h, mass}$	highest value of β_h in degrees for which mass flow is ensured
$\beta_{ho, max}$	highest inclination to the vertical in the oblique hopper
$\beta_{ho, min}$	steepest inclination to the vertical in the oblique hopper
β_n	intercept angle of an internal flow channel within the stored solid with the silo wall
γ	upper characteristic value of the bulk unit weight of a particulate solid
γ_1	bulk unit weight of fluidized stored particulate solid
γ_U	upper characteristic value of the unit weight (specific weight) of liquid
δ	coefficient of variation of a property (= standard deviation / mean)
θ	circumferential angular coordinate
θ_c	eccentric flow channel wall contact angle (circumferential coordinate of the edge of the low-pressure zone under eccentric discharge)
κ_{AAC}	load modifying factor for action assessment class
κ_{ar}	load modifying factor for aspect ratio (h_c/d_c)
κ_H	load modifying factor for normal pressures on vertical silo walls
$\kappa_{H,M}$	load modifying factor for normal pressures on vertical silo walls under mass flow
$\kappa_{H,X}$	load modifying factor for normal pressures on vertical silo walls under mixed flow
κ_{FG}	load modifying factor for flow group of the stored solid
κ_{ee}	load modifying factor for eccentricity of discharge
κ_{ef}	load modifying factor for eccentricity of filling
κ_T	load modifying factor for frictional traction pressures on vertical silo walls
$\kappa_{T,M}$	load modifying factor for frictional traction pressures on vertical silo walls under mass flow
$\kappa_{T,X}$	load modifying factor for frictional traction pressures on vertical silo walls under mixed flow
κ_U	load modifying factor for the usage of the silo (storage or process)
κ_V	load modifying factor for vertical stresses in the solid
κ_Z	load modifying factor combining κ_{AAC} , κ_U and κ_{ar} for convenient usage

μ	characteristic value of coefficient of wall friction for a vertical wall
μ_{heff}	effective or mobilized friction in a shallow hopper
μ_h	coefficient of wall friction for hopper
μ_m	mean value of coefficient of wall friction between a particulate solid and the wall
ν	Poisson's ratio for the stored solid
σ_r	reference stress level for solids testing
ϕ_c	characteristic value of unloading angle of internal friction of a particulate solid
ϕ_i	characteristic value of loading angle of internal friction of a particulate solid
ϕ_{im}	mean value of the loading angle of internal friction
ϕ_r	angle of repose of a particulate solid (conical pile)
ϕ_w	wall friction angle ($= \arctan(\mu)$) between a particulate solid and the silo wall
ϕ_{wh}	hopper wall friction angle ($= \arctan(\mu_h)$) between a particulate solid and the hopper wall
$\phi_{\text{wh, mass}}$	highest hopper wall friction angle ϕ_{wh} that can ensure mass flow in the silo
χ_L	loading modulus contiguity coefficient
χ_U	unloading modulus contiguity coefficient
ψ	eccentric flow channel wall contact angle measured from flow channel centre

4 Classification of silos

4.1 Action Assessment Classes for silos

(1) Different levels of rigour should be used in the evaluation of loads on silo structures, depending on the appropriateness of the load model used, the structural arrangement and the susceptibility to different failure modes.

NOTE In all the following classifications, the term silo refers to an isolated structure or to a single cell in a silo battery (see 3.2.60).

(2) To account for the uncertainty in determining actions with appropriate precision, silos should be classified into Action Assessment Classes according to their susceptibility to different failure modes.

NOTE 1 This classification can depend on:

- The overall geometry of the silo (slender or squat, etc.);
- The eccentricity of the filling trajectory and its possible wall impact;
- The eccentricity of the outlet and its effect on flow channels;
- The plan form of the silo cross-section, the corresponding shape of the hopper, the flexibility of non-circular planform walls, and the effects of eccentricities of filling and discharge;
- The duration of storage (whether short term or long term);
- The form of discharge equipment (fluidisation, conveyor, screw feeder, free fall, etc.)

NOTE 2 The listed criteria are intended to cover the different stored solids, different particle sizes and shapes, different aspect ratios, different modes of operation of the facility, different frequency of usage and the different modes of failure of silos constructed using different materials and having different structural forms.

NOTE 3 Illustrative examples of silos in different Action Assessment Classes are given in Table 4.1.

NOTE 4 Descriptions with quantified limits for different flow groups are given in Table 4.2 (NDP) unless the National Annex gives different descriptions and quantified limits. See Annex D for the classification of a solid into a flow group.

Table 4.1 — Action Assessment Classification (AAC) for silos

Action Assessment Class	Description	Illustrative examples
Action Assessment Class 4	Highest	Silos, or aspects of silos, that lie outside the limitations defined in 1.3 for which special considerations or supplementary information is required
Action Assessment Class 3	Higher	Large silos of high aspect ratio Large silos with extreme eccentricities of filling or discharge Large silos storing powders or solids that present handling difficulties because of poor solids flow Large squat silos in which the top surface is highly eccentric
Action Assessment Class 2	Normal	Typical silos with limited eccentricities of filling and discharge
Action Assessment Class 1	Lower	Small silos storing free-flowing solids and with concentric filling and concentric discharge
Action Assessment Class 0	Lowest	Silos with a very small stored mass

Table 4.2 (NDP) — Descriptions and quantified limits for Action Assessment Classes for silos

Action Assessment Class (AAC)	Descriptions and quantified limits
Action Assessment Class 4	Silos for which the action assessment requires additional considerations beyond the scope of this standard (outside the limitations given in 1.3) including solids in Flow Group D (see Annexes C and D)
Action Assessment Class 3	Silos that do not exceed the limitations described in 1.2 but meet the following conditions: Silos storing solids in Flow Groups A and B with stored mass in excess of 10 000 tonnes Very slender silos storing solids in Flow Groups A and B with stored mass in excess of 500 tonnes Slender silos storing solids in Flow Groups A and B with stored mass in excess of 1000 tonnes that have eccentric discharge with $e_o/d_c > 0,125$ Silos storing solids in Flow Groups A and B with stored mass in excess of 200 tonnes with eccentric discharge with $e_o/d_c > 0,25$ Silos storing solids in Flow Group C with stored mass in excess of 200 tonnes Squat silos with top surface eccentricity with $e_t/d_c > 0,25$
Action Assessment Class 2	All silos covered by this standard and not placed in another class
Action Assessment Class 1	Silos with stored mass between 2 and 50 tonnes, irrespective of eccentricities and the Flow Group of the stored solid
Action Assessment Class 0	Silos with stored mass below 2 tonnes, irrespective of eccentricities and the Flow Group of the stored solid
NOTE The differentiation made in this table is made in relation to the uncertainty in determining actions with appropriate precision. Rules for small silos are simple and conservative because small silos have an inherent structural robustness, and the high cost of particulate solids testing is not justifiable. The consequences of structural failure and the risk to life and economic loss are covered by the Consequence Classifications of EN 1990.	

(3) For silos in Action Assessment Class 1 (AAC1), simplified provisions may be adopted where indicated in this standard.

(4) For silos in Action Assessment Class 0 (AAC0), the rules for Action Assessment Class 1 may be used, but they are not formally required to be used.

(5) For silos in Action Assessment Class 4 (AAC4), additional information beyond that given in this standard shall be obtained.

(6) A higher Action Assessment Class than required in (2), may be adopted and any part of the procedures for a higher Action Assessment Class may be adopted whenever it is appropriate.

(7) The choice of Action Assessment Class may be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

4.2 Silo usage classes

(1) Silos should be classed according to the frequency with which extreme load conditions can arise.

NOTE 1 The classification relates to the filling and emptying processes, which affect both loads from stored solids and the probability of the silo being empty when a wind design situation arises.

NOTE 2 Since the safety evaluations of Eurocode standards are based on the probability of particular design situations arising within a defined time period, it is necessary to make this distinction to ensure adequate safety for silos subject to statistically frequent occurrences of a design situation, whilst permitting appropriate economy for those for which the probability of design conditions occurring is much lower.

(2) A distinction should be made between storage silos and process silos.

NOTE See 3.2 for their definitions.

(3) Silos that are repeatedly partially filled and partially emptied, with their contents changing regularly, should not be classed as storage silos.

(4) The classification of a silo as either a storage silo or a process silo may be agreed for a specific project by the relevant parties.

5 Design situations and modelling of actions

5.1 General

(1) Actions on silos and tanks should be determined by considering the different design situations which can occur during operation of the facility, including transient and persistent loads associated to filling and discharge.

5.2 Representation of loads on silos

5.2.1 General

(1) Silo load cases shall be selected depending on the structural consequences and potential modes of structural failure of the silo.

(2) The magnitudes and distribution of actions on silos should be determined taking account of the silo structure, the stored solid properties, the filling process and the discharge flow patterns that arise during the process of emptying.

NOTE The magnitude and distribution of the design loads depend on the silo structural form, the stored solid properties, the filling process and the discharge flow patterns that arise during the process of emptying. The inherent variability of particulate solids and simplifications in the load models used in this standard lead to differences between actual silo loads and loads given by the design rules. For example, the distribution of discharge pressures throughout the wall varies as a function of time and no accurate prediction of the mean pressure or its variance is currently possible.

(3) Silo loads defined in prEN 1991-4 should be treated as characteristic loads.

NOTE 1 The characteristic value of actions on silos defined in this standard are intended to correspond to values that have a probability of 2 % that they will be exceeded within a reference period of 1 year.

NOTE 2 The characteristic values of silo loads are nominal values. They are not based on a formal statistical analysis because such data are currently not available. Instead, they are based on historical values used in earlier standards, experience from practice and interpretation of research findings. The above description corresponds to that given in EN 1990 which allows for nominal values to be used.

NOTE 3 The definitions given in EN 1990 chiefly relate to natural events that occur with frequencies unaffected by human choice. By contrast, silo loading is largely unaffected by natural events but is instead affected by operational choices. Silos that are used in a facility where they are filled and emptied every day are more likely to experience the characteristic values of loading used for design than those that are only completely filled and emptied annually or irregularly.

NOTE 4 The load cases to be considered for a silo depend on the structural consequences and potential modes of structural failure of the silo.

5.2.2 Representation of loads on silo inside surfaces

(1) The loads on the silo wall surfaces should be represented by pressures and frictional tractions that vary spatially and are caused by the stress state in the stored solid.

NOTE In this standard, the stress state in the stored solid is referred to as a “stress”. The distributed force transferred to the silo wall surfaces is referred to as a “pressure”.

(2) Particulate solids loads on silos should be expressed in terms of a horizontal pressure p_h on the inner surface of the vertical silo wall, a normal pressure p_n on an inclined wall, with frictional tractions on the walls p_w and p_t , and a vertical stress p_v in the stored solid.

NOTE The loads on flat bottoms and on tie rods within silos are derived from the above principal components.

(3) Load patterns for filling and discharge should be used as load cases in considering design situations at the ultimate and serviceability limit states.

(4) The load cases should be considered on the basis of the flow characteristics of the stored particulate solid, as determined in accordance with Annex D. For all the relevant design situations, the appropriate load cases should be identified.

(5) Loads on silos from the stored solid should usually be considered when the silo is in the full condition.

NOTE For situations with high filling eccentricity, it is possible for the most critical design condition to occur when the silo is not full.

5.2.3 Classification of actions on silos

(1) Loads on silos from stored particulate solids during filling or discharge should be classified as fixed variable quasi-static actions for the loads cases specified in 7, 8, 9 and 10 unless otherwise defined.

(2) Discharge loads specified in 7.2.4 (band loads) should be classified as free variable quasi-static actions.

(3) Discharge loads specified in 8.3 (proxy loads) should be classified as free variable quasi-static actions.

(4) Discharge loads specified in 8.4 (large flow channel eccentricity) should be classified as free variable quasi-static actions concerning the circumferential position of the flow channel unless a specific position can be ensured based on a fixed position of the outlet.

(5) Gas pressure loads attributable to pneumatic conveying systems should be classified as fixed variable static actions.

(6) Loads due to dust explosions should be classified as fixed variable accidental dynamic actions.

(7) Loads due to differential thermal expansion should be classified as fixed variable accidental static actions.

(8) Loads due to filling silos with hot solids should be classified as fixed variable quasi-static actions.

(9) Loads due to swelling of stored solids should be classified as accidental fixed variable quasi-static actions.

(10) Loads due to reduced or increased air pressure due to inadequate venting should be classified as fixed variable accidental quasi-static actions.

(11) Where a discharge aid (including an anti-dynamic tube against the wall) is installed, the silo should be designed for the flow pattern that the flow aid manufacturer guarantees. If agreed between the relevant parties, malfunction of the safety valves should be considered by using an appropriate load case classified as accidental.

(12) Where a discharge flow aid device is installed, the silo should be designed for the flow pattern that the flow aid manufacturer guarantees. If agreed between the relevant parties, malfunction of the discharge aid should be considered by using an appropriate load case treated as accidental.

5.2.4 Evaluation of loads on silos

(1) The evaluation of loads due to stored solids on a silo should take account of:

- the geometry of the silo;
- the range of particulate solid properties;
- variation in the coefficient of friction on different parts of the silo wall;
- the methods of filling and discharge.

(2) The upper characteristic value of the bulk unit weight γ should be used in all load calculations.

(3) Loads on the internal surfaces of the silo structure should initially be treated as symmetrical and evaluated using the mechanical properties of the specific solid to be stored.

(4) Since the properties of any solid inevitably vary from time to time, a range of properties, as defined in 6.1 (9), should be used to address the different stress resultants that can develop in the silo walls.

(5) For silos in AAC1, a simpler treatment of variability of stored solid properties may be adopted, using mean values of all the properties of the solid except the unit weight, but a higher load modifying factor is applied (Formula (5.14)) to ensure that the variability of the solid is addressed.

(6) The evaluation of each load case should be made using a single set of consistent values of the solids properties (wall friction coefficient μ , lateral pressure ratio K and internal friction angle ϕ_i), so that each limit state corresponds to a single defined stored solid condition (see 6.1).

(7) The magnitude of the applied loads for silos shall be based on the flow characteristics of the stored particulate solid, as determined in accordance with Annexes C and D.

(8) Because the loads on the walls of silos are not entirely symmetrical, the loss of symmetry should be accounted for in the design.

(9) Where the filling and/or discharge of solids involves only a small eccentricity, the extent of this loss of symmetry is addressed by changes in load modifying factors that depend on the specific geometry and stored solid, see 5.6.

(10) Where the well-defined conditions of small eccentricities in 5.3.3 are not met, the effects of unsymmetrical pressure patterns that arise should be represented by Silo Special Load Cases, as defined in 5.5.

(11) If the structural form selected for the silo is likely to be sensitive to deviations in load patterns, a sensitivity analysis should be performed.

(12) Special consideration should be given to loads in specific silo construction forms or in silos in particular circumstances, as defined in 5.5.

(13) Where vibrations caused by machinery can be transferred into the stored solid, or where it is established that the bulk unit weight can be increased by other external influences, consideration should be given to adopt a higher unit weight than the upper characteristic value for the particulate solid. Where appropriate, vibration tests on a sample of the solid should be conducted to establish the potential for such increases.

5.2.5 Silo Fundamental and Special load cases

(1) A distinction is made between fundamental and special load cases depending on the structural consequences and potential modes of structural failure of the silo. Silo Fundamental Load Cases relate to relatively simple silos with symmetrical filling and discharge and storing solids with good handling properties. Silo Special Load Cases relate to more complex conditions, which can arise in silos that are not concentrically filled and concentrically emptied.

(2) The Silo Fundamental Load Cases should be adopted for all silos, even when a Silo Special Load case will also apply.

(3) Special circumstances arise in some silos, leading to very different load cases from those of common symmetrical loading conditions and should be adopted when the relevant conditions can arise. These are termed “Silo Special Load Cases (SSLC)” and the loading conditions are defined in Clauses 8 and 10 for use when the particular relevant circumstances arise only in Action Assessment Classes 2 and 3. These load cases are not needed for silos in Action Assessment Class 1, or in conventional silos that are filled and discharged concentrically. They are also not needed for silos that do not contain solids in Flow Groups C or D (see Annex D, D.2 and D.3) and have an aspect ratio below $h_c/d_c = 4,0$. Some of these special load cases apply only to silos of circular planform.

(4) The ultimate resistance of a silo structure is extremely sensitive to load cases involving any loss of symmetry, whether intentional or accidental. These conditions should be carefully assessed in the design, especially when the aspect ratio is higher, or the stored solid is badly behaved and/or the silo is large. To address this challenge, this standard has three clear distinctive treatment paths as outlined below.

(5) The first path, for load cases that are symmetrical or close symmetrical (see Table 5.2), the simple classic load model is retained, but it is adjusted by the use of partial factors that depend on the stored solid, the aspect ratio, the small filling and discharge eccentricities, and the mode of operation. These conditions are termed the Silo Fundamental Load Cases. The relevant calculations are set out in Clauses 7 and 9. This straightforward treatment should be adopted when relevant to retain simplicity for the subsequent structural design.

(6) Where a filling or discharge eccentricity exceeds the value defined for small eccentricities in Table 5.2 and is classed as moderate eccentricity, relate to more complex conditions, as identified in 5.4. Depending on the stored solid, a simple unsymmetrical load model is permitted to function as a proxy for the real, much more complicated loading that occurs. The proxy unsymmetrical loads are defined as simple Silo Special Load Cases and covered in Clauses 8 and 10. This second treatment is, however, completely inadequate for cases involving large eccentricities (see Table 5.2). These treatments should be adopted when the relevant circumstances arise.

(7) The third path is also termed a Silo Special Load Case, but it relates to cases involving large eccentricities of filling and or discharge (see Table 5.2) as well as other distinctly different situations, and for these the special mechanics-based load models should be adopted. This is also covered in Clauses 8 and 10.

(8) The appropriate paths through the standard, separately for vertical walls and hoppers, are clearly set out in the corresponding flow charts in Annex G.

5.2.6 Design situations for specific silo construction forms

(1) Special consideration should be given to specific silo construction forms in particular circumstances.

NOTE This subclause addresses many disparate items for different conditions.

(2) In all circular silos subjected to unsymmetrical pressure conditions, careful provision should be made to ensure that the upper edge of a cylindrical wall is held circular by attachment to a stiff roof or the provision of a stiff ring.

NOTE Under unsymmetrical loads, the distortion of the circular cross section can lead to a considerable loss of resistance.

(3) In concrete silos being designed for the serviceability limit state, cracking should be limited to prevent water ingress at any time. The crack control should comply with the crack width limitations of EN 1992 appropriate for the environment in which the silo is situated.

(4) In metal silos that are assembled using bolted or riveted construction, the variability in the spatial positions of these loads should be recognized when applying the provisions for free loads (proxy loads and band loads).

(5) In metal silos that have a rectangular planform and contain internal ties to reduce the bending moments in the walls, the provisions of 8.8.2 should be used.

(6) The design service life should be used for the purposes of a fatigue assessment. One load cycle should be considered to comprise a single complete filling and emptying or, in an aerated silo (Figure 5.9c), a complete sequence (rotation) of aerated sectors. The effects of fatigue should also be considered in silos affected by vibrating machinery.

(7) Prefabricated silos should be designed for actions arising during handling, transport and erection.

(8) Where a manhole or access opening is made in the wall of a silo structure, the pressure acting on the cover should be determined as two times the highest value of the local design pressure on the adjacent wall. This pressure should be used only for the design of the opening cover and its supports.

(9) Where the roof supports dust filter assemblies, cyclones, mechanical conveying equipment or other similar items, these should be treated as self-weight if they are permanent, or as imposed loads if they are only temporary.

(10) Where pneumatic conveying systems are used to fill or empty the silo, the resulting positive or negative internal gas pressure should be considered. If agreed between the relevant parties, a malfunction of the safety valves should be considered in the design, using an appropriate load case treated as accidental.

NOTE These pressures are usually controlled by safety valve settings that are defined in the design documentation. Appropriate relief protection is necessary in silos to account for such unexpected events, unless the silo design ensures that they cannot occur.

(11) Where vibrators, conveying systems, air cannons or gyrating live bottoms form part of the silo installation, the alternating loads caused by them should be considered with respect to the limit state of fatigue. The relevant information for the design calculations should be agreed by the relevant parties.

(12) Where it is proposed to modify an existing silo by the insertion of a wall liner, the consequences of the modified wall friction for the structural design should be investigated, including possible structural consequences of changes in the solids flow patterns.

5.3 Evaluation of filling and discharge conditions for silos

5.3.1 General

(1) Different silo aspect ratios (slenderness's), hopper geometries and discharge arrangements lead to different design situations for both filling and discharge that should be considered.

(2) The design should consider the consequences of the flow pattern during discharge, which are described in terms of the following basic categories (see Figure 5.1 for symmetrical patterns):

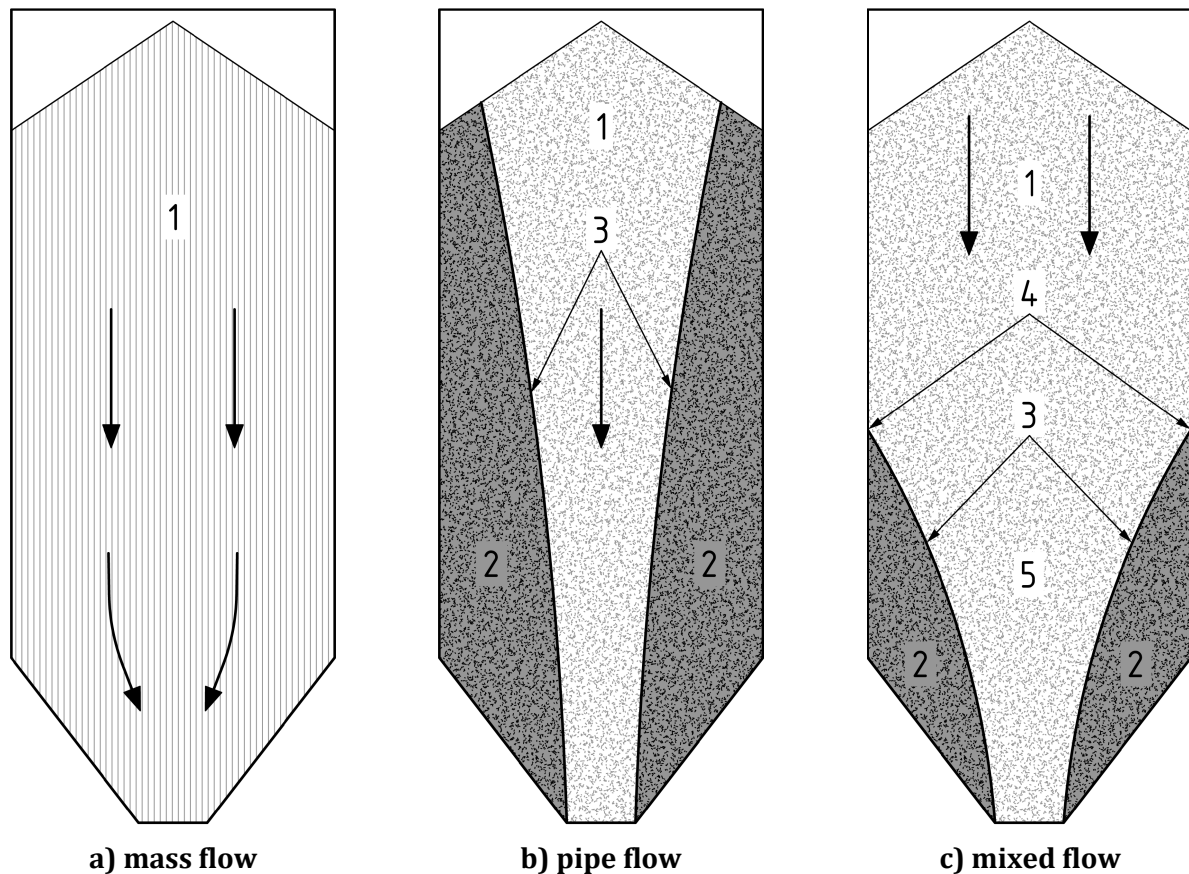
- mass flow;
- pipe flow;
- mixed flow.

(3) As the relevance of the different flow patterns depends very strongly on the silo aspect ratio (see Figure 5.2), the aspect ratio should be chosen depending on the functional requirements of the silo, the site conditions, and the need to address more complex loading conditions (see 5.5).

(4) The type of symmetrical flow pattern (mass flow, mixed flow or pipe flow) should be determined using the provisions in 5.3.2 check.

NOTE Where symmetrical pipe flow is ensured, no serious increase in symmetrical pressure above the values for filling usually occurs. Where symmetrical mass flow is ensured, only small increases in symmetrical pressure above the values for filling usually occur. However, where nearly symmetrical mixed flow occurs (see Figure 5.1c), significant increases in symmetrical pressure and vertical wall compression above the values for filling at different locations on the wall take place.

(5) In situations where control of the flow pattern is essential to the functional design, consideration should be given to special wall friction measurements according to Annex D, D.12.

**Key**

- 1 All solids in motion
- 2 Solids stationary
- 3 Flow channel boundary
- 4 Effective transition
- 5 Effective hopper

NOTE Both pipe flow and mixed flow are classed as funnel flow.

Figure 5.1 — Basic symmetrical flow patterns

NOTE 1 Although steeper hoppers are usually required for mass flow and shallower hoppers produce funnel flow, the images in Figure 5.1 have all retained the same hopper slope to emphasize the dependence of the flow pattern on the hopper wall friction coefficient and the angle of internal friction of the solid.

NOTE 2 Further information concerning the effects of particulate solid properties on the developed flow pattern is given in Annex D.

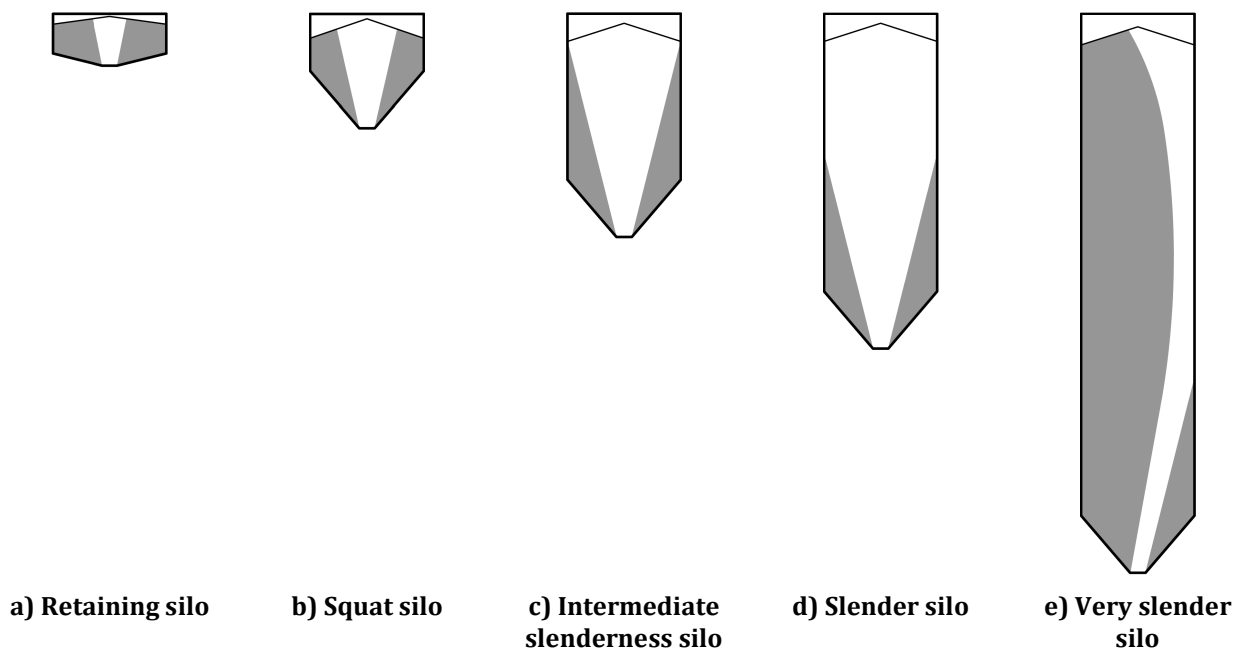


Figure 5.2 — Aspect ratio (slenderness) effects in pipe and mixed flow patterns

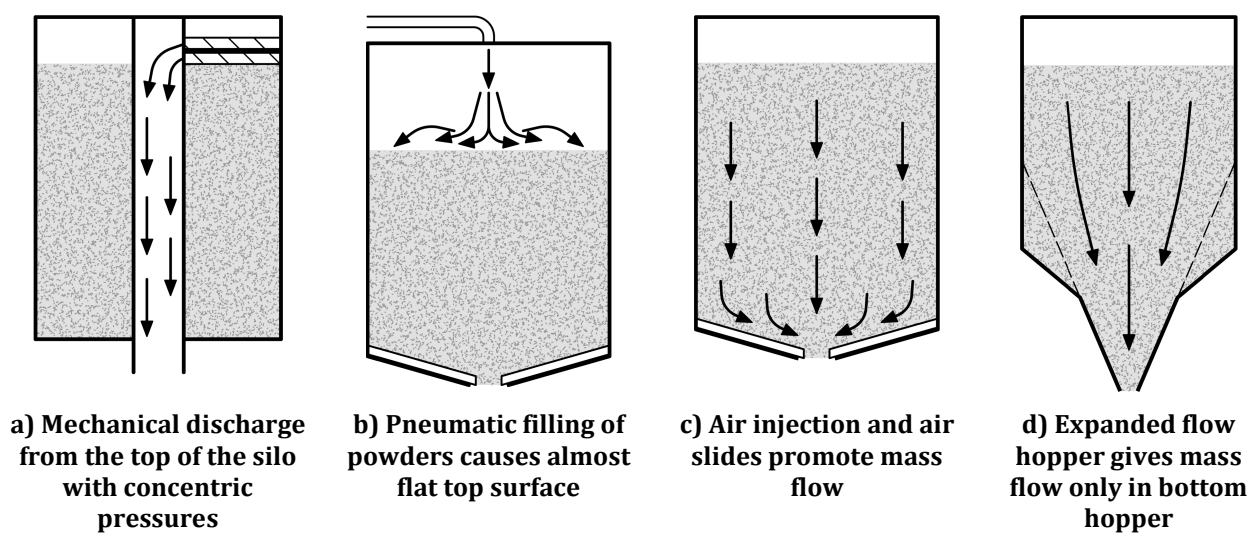


Figure 5.3 — Some less common symmetrical filling and discharge arrangements

5.3.2 Prediction of symmetrical flow patterns

(1) Mass flow (Figure 5.1a) may be considered to be ensured if the hopper wall friction angle ϕ_{wh} (in degrees) is less than the limiting value $\phi_{wh, mass}$ associated with the hopper apex half angle β_h , (in degrees) (Figure 5.4), given by:

$$\phi_{wh, mass} = f_0 + f_1 \beta_h + f_2 \beta_h^2 \quad (5.1)$$

in which:

$$f_0 = 22 + 0,28\phi_i \quad (5.2)$$

$$f_1 = 1,03 - \frac{\phi_i}{16} + \left(\frac{\phi_i}{36}\right)^2 \quad (5.3)$$

$$f_2 = -0,027 + \frac{\phi_i}{760} - \left(\frac{\phi_i}{220}\right)^2 \quad (5.4)$$

where:

$\phi_{wh, mass}$ is the highest value of ϕ_{wh} in degrees for which mass flow is ensured;

β_h is the hopper apex half angle in degrees;

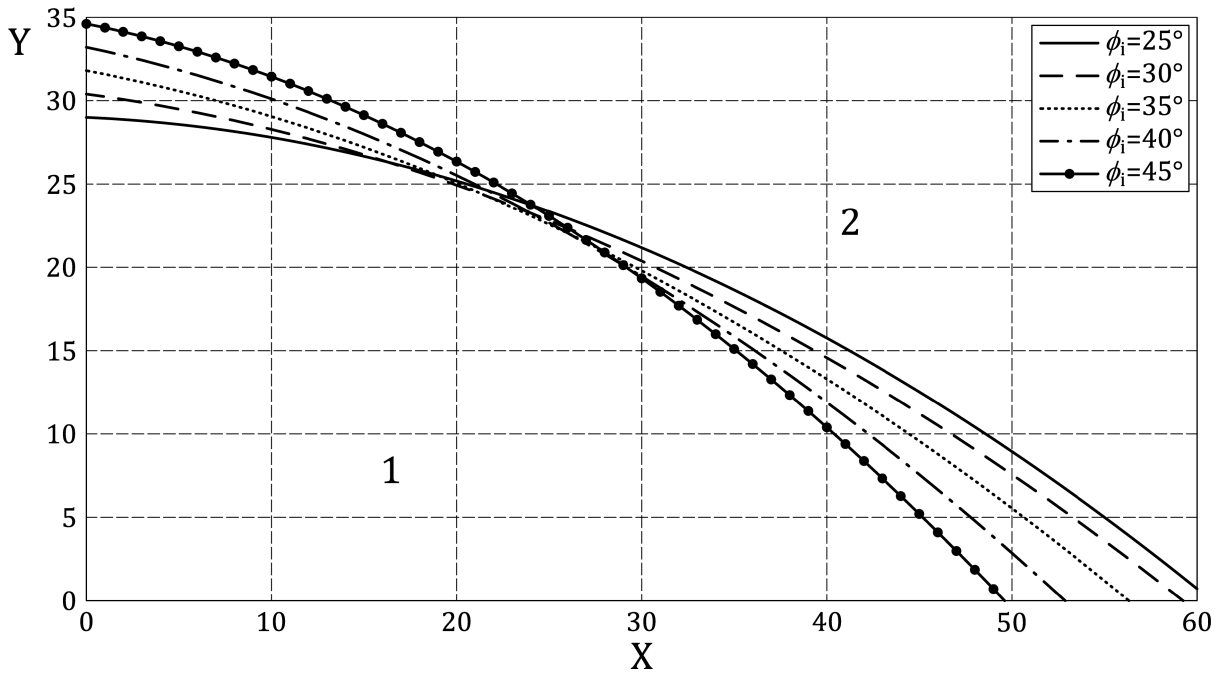
ϕ_i is the relevant angle of internal friction of the solid in degrees, defined in (15).

NOTE 1 Where the wall friction of the solid on the hopper has been specified by its hopper wall friction coefficient μ_h (see Annex C), the appropriate value of ϕ_{wh} can be found as $\phi_{wh} = \arctan(\mu_h)$.

NOTE 2 Where the value of ϕ_{wh} has been derived from the value of μ_h in Annex C and following the rules of 6.1 (9), the upper characteristic value of μ_h is required to determine whether mass flow can be achieved.

(2) Where the hopper half angle β_h exceeds 22° , the upper characteristic value of ϕ_i should be adopted. Where the hopper half angle β_h is less than 22° , the lower characteristic value of ϕ_i should be adopted (see 6.1 and Annex C).

NOTE The choices of different characteristic values for different ranges of hopper slope produces a safe estimate of the conditions in which mass flow can be reliably predicted.



Key

X Angle of inclination of hopper wall measured from the vertical, or the shallowest slope on a square or rectangular pyramidal hopper (valley angle) β_h (in degrees)

Y Wall friction angle for the hopper ϕ_{wh} (in degrees)

1 Mass flow

2 Funnel flow (see Figure 5.1 b and c)

NOTE In the zone close to the limit of mass flow, the mode of flow is more difficult to predict (see also 1.2(18)).

Figure 5.4 — Conditions in which mass flow or funnel flow is likely in conical hoppers

(3) Where the hopper is wedge shaped (converging in only one dimension), mass flow may be considered to be ensured (Figure 5.5) if the hopper steepness, expressed in terms of the apex half angle β_h in degrees, is less than $\beta_{h, \text{mass}}$ given by:

$$\beta_{h, \text{mass}} = \frac{(446^\circ - 1,52\phi_i)}{(228^\circ + \phi_i)} \{37,6^\circ + 0,165\phi_i - \phi_{wh}\} \quad (5.5)$$

where ϕ_i and ϕ_{wh} are both expressed in degrees and subject to the constraint that the value of ϕ_{wh} used in Formula (5.5) should not be greater than $\phi_{wh, \text{lim}}$ where $\phi_{wh, \text{lim}}$ is given by

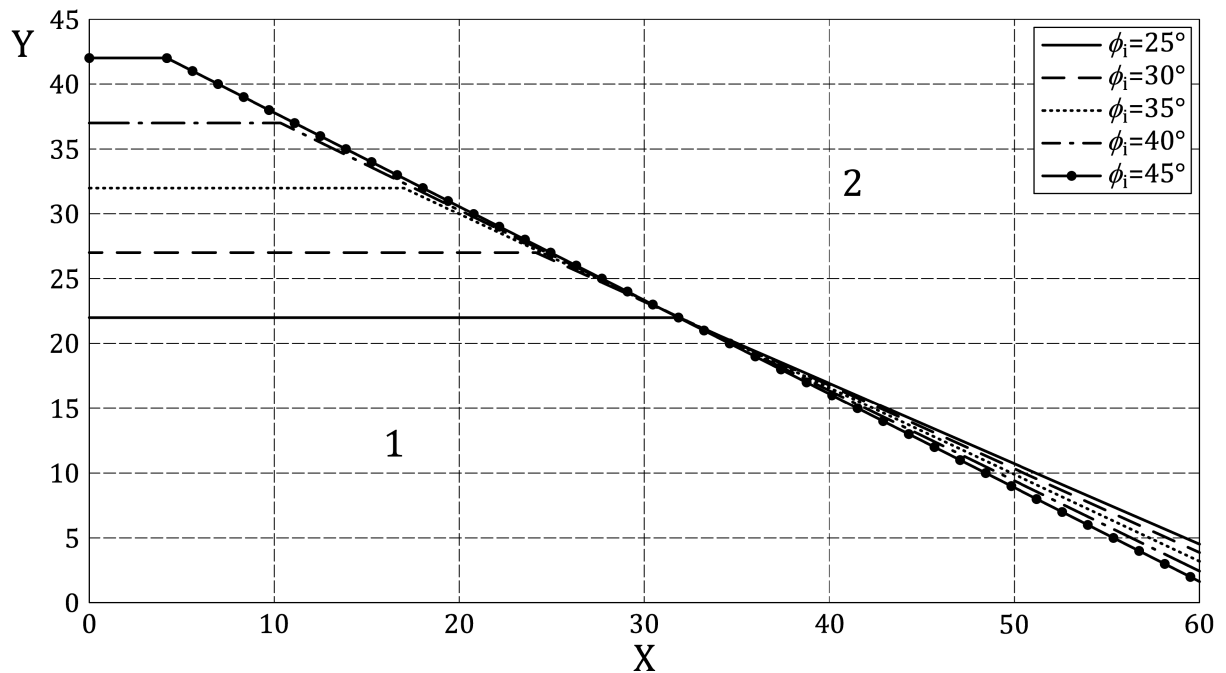
$$\phi_{wh, \text{lim}} = \phi_i - 3^\circ \quad (5.6)$$

where:

ϕ_i is the lower characteristic value of the angle of internal friction ϕ_i in degrees;

ϕ_{wh} is the upper characteristic value of the hopper wall friction angle ϕ_{wh} in degrees.

(4) Pipe flow may only be considered to be guaranteed in wedge hoppers if the hopper apex half angle exceeds 65° .



Key

X Angle of inclination of hopper wall measured from the vertical β_h (in degrees)

Y Wall friction angle for the hopper ϕ_{wh} (in degrees)

1 Mass flow

2 Funnel flow (see Figure 5.1b and c)

NOTE In the zone close to the limit of mass flow, the mode of flow is more difficult to predict (see also 1.2 (18)).

Figure 5.5 — Conditions in which mass flow or funnel flow is likely in wedge-shaped hoppers

5.3.3 Assessment of the filling and discharge eccentricities

(1) The eccentricity of the outlet e_o should be taken as the eccentricity of the centre of the outlet, as shown in Figure 5.6c.

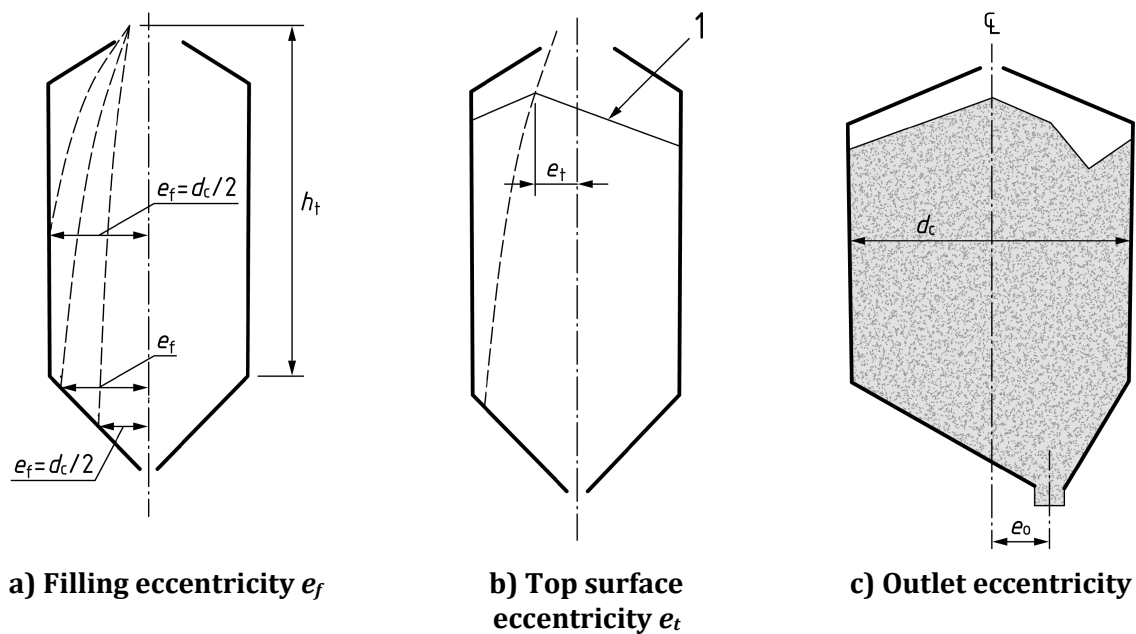
(2) The eccentricity of filling should be assessed as defined below on the basis of the trajectory of the incoming solids, as indicated in Figures 5.6a and 5.6b.

(3) Where the filling is undertaken using a vertical chute, the filling eccentricity e_f should be taken as equal to the eccentricity of the chute x_i .

(4) For all other inlet arrangements, the trajectory of the solid falling into the silo should be determined as follows. The horizontal location of the point at which the solid stream leaves the inlet chute should be identified as x_i from the silo centreline (Figure 5.7), the vertical location should be identified as the origin for the calculation of the solids trajectory and the horizontal and vertical velocity of the solid at the end of the chute should be identified as u_o and v_o respectively (Figure 5.7).

NOTE 1 Solid impacting the wall at any level can lead to a significant increase in the asymmetry of wall pressures, arising from polishing or abrasion, together with a higher packing unit weight adjacent to the wall at that location.

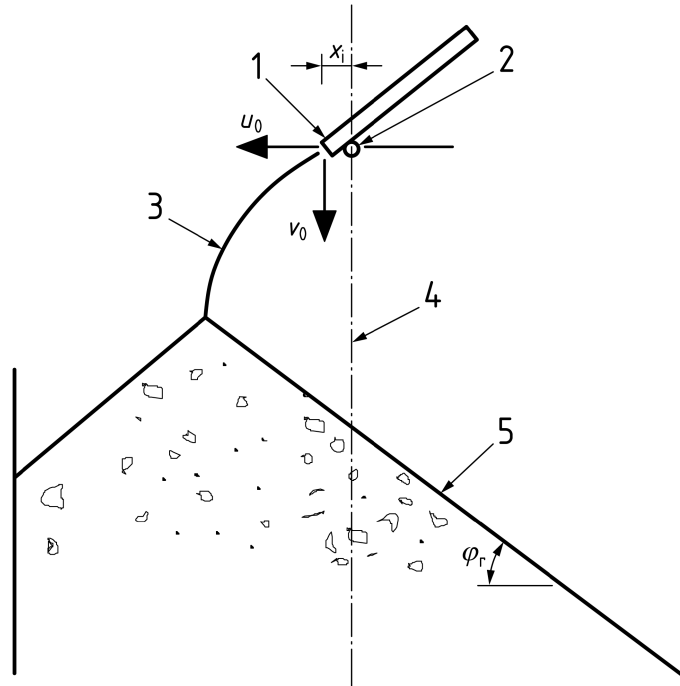
NOTE 2 The degree of filling eccentricity has a significant influence on the loads and thereby the safety of the silo, and it is important that information on the intended filling trajectory during operation be communicated by relevant parties in the early stages of design.



Key

- 1 Top surface when the silo is full

Figure 5.6 — Eccentricities of filling and discharge

**Key**

- 1 End of filling chute
- 2 Origin of coordinates
- 3 Trajectory of solids
- 4 Centreline of silo
- 5 Conical pile of solids

Figure 5.7 — Notation for evaluation of the filling eccentricity

(5) In conditions where the horizontal velocity is high and the silo is tall, the stream of particles will strike the vertical wall provided that

$$h_t > h_{t,\text{lim}} \quad (5.7)$$

where:

$$t_t = \frac{(d_c / 2) - x_i}{u_0} \quad (5.8)$$

$$h_{t,\text{lim}} = v_0 t_t + g t_t^2 / 2 \quad (5.9)$$

and:

g is the acceleration of gravity;

h_t is the height of the end of the chute above the silo transition (Figure 5.6a).

(6) Where Formula (5.7) is satisfied, the eccentricity of filling should be taken as

$$e_f = d_c / 2 \quad (5.10)$$

and the rules of 8.3 using proxy loads to simulate significant loss of symmetry should be adopted.

(7) Where Formula (5.7) is not satisfied, the filling eccentricity may be taken as

$$e_f = x_i + \frac{u_0 v_0}{g} \left[\left(1 - \frac{2gh_t}{v_0^2} \right)^{1/2} - 1 \right] \quad (5.11)$$

where:

- x_i is the eccentricity of end of filling tube;
- u_0 is the horizontal velocity at the end of filling tube;
- v_0 is the vertical velocity at the end of filling tube.

(8) The assessed eccentricity of filling e_f should be used with the criteria for eccentric filling given in Table 5.2.

(9) If Table 5.2 does not require a Silo Special Load Case for a small or large filling eccentricity to be used, the filling may be deemed to be concentric, and the simple provisions of 7 for concentric filling may be adopted.

(10) Where the silo is of squat or intermediate slenderness, the assessed eccentricity of filling e_f according to Table 5.2 should be used to determine if the Silo Special Load Case of eccentric filling is required.

5.3.4 Silos storing powders

(1) Where a silo is filled with powder that has been pneumatically conveyed, the following two design situations for the full condition should be considered:

- the stored solid can form an angle of repose, as for other solids;
- the top surface can be horizontal (see Figures 5.3b, c and d), irrespective of the angle of repose and the eccentricity of the filling process.

(2) Where the top surface is deemed to be horizontal, the eccentricities associated with filling e_f and e_t (Figures 5.6a and b) may be taken to be zero, and the filling level should be taken at its highest possible value.

5.4 Silo Fundamental Load Cases (SFLC)

5.4.1 Common failure modes

(1) In general, for the fundamental load cases, at least four different conditions should be considered, corresponding to the four common failure modes related to vertical walls and hopper walls:

- bursting or cracking due to excessive pressures normal to a silo vertical wall;
- buckling or yielding due to excessive vertical compressive stresses in the silo wall;
- rupture of a hopper body due to excessive normal pressures on the hopper wall from the stored particulate solid;

- rupture of a hopper top due to excessive loads from the total mass of the stored particulate solid or rupture of horizontal hopper seams due to excessive frictional forces on the hopper wall.

NOTE 1 These rules apply only to conditions in which symmetry is carefully ensured by both the filling and discharge arrangements.

NOTE 2 Situations leading to systematically unsymmetrical pressures are set out in 5.2.3 and 5.5.

5.4.2 Eccentricity limits for Silo Fundamental Load Cases

(1) The limitation of the eccentricities of filling and discharge for a silo to be only treated using Silo Fundamental Load Cases are given in Table 5.1 and depend on the relative slenderness of the silo.

(2) For silos in AAC2 and AAC3 that do not satisfy the eccentricity limits defined in Table 5.1, additional load cases should be considered as defined in 5.5.

(3) The filling loads are only affected by the eccentricity of filling e_f defined in 5.3.3.

(4) The eccentricity of discharge e_e should be taken as the larger of the filling and discharge eccentricities as

$$e_e = \max(e_f, e_o) \quad (5.12)$$

Table 5.1 — Eccentricity limits for Silo Fundamental Load Cases

	Slender and very slender silos	Intermediate slenderness silos	Squat silos
Small filling eccentricity	$e_f < 0,30d_c$	$e_f < 0,20d_c$	$e_f < 0,20d_c$
Small discharge eccentricity	$e_e < 0,15d_c$	$e_e < 0,20d_c$	$e_e < 0,30d_c$

(5) Additional information should be sought when dealing with the following situations, which are not covered by this standard (AAC4):

- specific environmental conditions with respect of humidity, and both interstitial air or wall surface temperature, can change the bulk material properties and wall friction coefficient, or
- attainment of the dew point at the wall can cause solid to stick to the wall and, in turn, an erratic and eccentric flow during discharge of the silo.

5.4.3 Uncertainty and variability of solid properties

(1) Where uncertainty concerning the particulate solid properties exists, testing of an appropriate sample of the solid considering the effects of temperature, humidity and time dependence should be undertaken and the possible variations included in the design.

NOTE Particulate solids known to exhibit unexpected behaviour as a consequence of parameter variations of this kind include soya meal, animal food pellets, coal with a significant clay content and cement.

(2) The variability of any stored solid means that different extremes in the range of each property should be considered to address failure modes listed in (1).

(3) For silos in AAC1, a simpler treatment of variability of stored solid properties may be adopted, using mean values of all the properties of the solid except the unit weight, but a higher load modifying factor is applied (Formula (5.14)) to ensure that the variability of the solid is addressed.

5.4.4 Types of Silo Fundamental Load Cases

(1) Two separate Silo Fundamental Load Cases should be considered for every vertical wall:

- Maximum normal pressure against the vertical wall;
- Maximum vertical frictional traction (shear force per unit area) on the silo vertical wall.

(2) Two separate Silo Fundamental Load Cases should be considered for a hopper wall:

- Maximum normal pressure against the hopper wall;
- Maximum frictional traction on the hopper wall.

(3) For the design of a flat bottom in a silo, only the following Silo Fundamental Load Case should be considered:

- maximum vertical pressure on the bottom.

(4) For each load case on both vertical walls and hoppers, the corresponding accompanying frictional traction or normal pressure associated with the adopted solids properties should be included. For silos in AAC2 and AAC3, the stored solid property extremes defined in 6.1 and Table 6.2 should be considered to produce up to six symmetrical load cases, according to the relevant conditions for the structure being designed.

(5) All silo vertical walls should be designed for loads caused by symmetrical filling and symmetrical discharge as follows:

- slender and very slender silos (see 7.2);
- squat and intermediate slenderness silos (see 7.3);
- retaining silos (see 7.4).

(6) All silo hopper walls should be designed for loads caused by symmetrical filling and symmetrical discharge as follows:

- a) steep hoppers (see 9.2);
- b) shallow hoppers (see 9.3);
- c) silos with flat bottoms (see 9.4).

(7) Where internal pipe flow can be guaranteed, the design may be based on filling loads alone.

(8) Where a silo is used to store solids in Flow Group D, the provisions of this standard should not be applied, unless discharge is achieved from the top (Figure 5.3a).

(9) For silos in AAC1 the Silo Fundamental Load Case (SFLC) for mixed flow (5.2.4) may be neglected.

(10) Where the silo has a rectangular vertical section with a conical hopper, and there is a rectangular to circular transition section between the two, the pressures on the wall of the transition section should be taken as those found as if the hopper were entirely conical.

(11) Where the silo has a hopper that is not conical, pyramidal, or wedge-shaped, an analysis of the pressures based on mechanics should be carried out. Where a hopper contains internal structures, the pressures on both the hopper and the internal structure should be evaluated based on mechanics and the hopper only should be treated as AAC4 (i.e. special information is required that is not provided in this standard).