DD ENV 1991-4:1996

Eurocode 1: Basis of design and actions on structures —

Part 4: Actions in silos and tanks

ICS 91.040

Committees responsible for this Draft for Development

The preparation of this Draft for Development was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/1, Actions (loadings) and basis of design, upon which the following bodies were represented:

British Constructional Steelwork Association
British Iron and Steel Producers' Association
British Masonry Society
Concrete Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property and Buildings Directorate)
Highways Agency
Institution of Structural Engineers
National House-building Council
Royal Institute of British Architects
Steel Construction Institute

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Contents

National foreword

This Draft for Development has been prepared by Subcommittee B/525/1 and is the English language version of ENV 1991-4:1995 *Eurocode 1: Basis of design and actions on structures — Part 4: Actions in silos and tanks* published by the European Committee for Standardization (CEN). This document does not have a parallel British Standard and, therefore, it has been published for use in the United Kingdom (UK) without any National Application Document.

ENV 1991-4:1995 results from a programme of work sponsored by the European Commission to make available a common set of rules for the structural and geotechnical design of buildings and civil engineering works. The full range of codes covers the basis of design and actions, the design of structures in concrete, steel, composite construction, timber, masonry and aluminium alloy, and geotechnical and siesmic design.

This publication is not to be regarded as a British Standard.

An ENV or European Prestandard is made available for provisional application, but it does not have the status of a European Standard. The aim is to use the experience gained to modify the ENV so that it can be adopted as a European Standard (EN).

For consideration of transformation of an ENV into an EN, it is important to get as much feedback as possible from practising engineers. Such feedback is therefore strongly encouraged and the users of this document are invited to comment on its technical content, ease of use and any ambiguities or anomalies. These comments will be taken into account when preparing the UK national response to CEN on the question of whether the ENV can be converted into an EN.

Comments should be sent in writing to the Secretary of Subcommittee B/525/1 at BSI, 389 Chiswick High Road, London W4 4AL, quoting the document reference, the relevant clause and, where possible, a proposed revision by September 1997. After this date, it will still be possible to comment through corporate bodies, such as engineering institutions.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 32 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

EUROPEAN PRESTANDARD

PRÉNORME EUROPÉENNE

EUROPÄISCHE VORNORM

ENV 1991-4

May 1995

ICS 91.040.00

Descriptors: Civil engineering, structures, design, construction, buildings codes, computation, loads, silos, tanks: containers

English version

Eurocode 1: Basis of design and actions on structures — Part 4: Actions in silos and tanks

Eurocode 1: Bases de calcul et actions sur les structures — Partie 4: Actions dans les silos et réservoirs

Eurocode 1: Grundlagen der Tragwerksplannung und Einwirkungen auf Tragwerke — Teil 4: Einwirkungen auf Silos und Flüssigkeitsbehälter

This European Prestandard (ENV) was approved by CEN on 1993-06-30 as a prospective standard for provisional application. The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into an European Standard (EN).

CEN members are required to announce the existence of this ENV in the same way as for an EN and to make the ENV available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the ENV) until the final decision about the possible conversion of the ENV into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. ENV 1991-4:1995 E

Foreword

Objectives of the Eurocodes

1) The Structural Eurocodes comprise a group of standards for the structural and geotechnical design of buildings and civil engineering works.

2) They cover execution and control only to the extent that is necessary to indicate the quality of the construction products, and the standard of the workmanship, needed to comply with the assumptions of the design rules.

3) Until the necessary set of harmonized technical specifications for products and for methods of testing their performance are available, some of the Structural Eurocodes cover some of these aspects in informative annexes.

Background to the Eurocode programme

4) The Commission of the European Communities (CEC) initiated the work of establishing a set of harmonized technical rules for the design of building and civil engineering works which would initially serve as an alternative to the different rules in force in the various member states and would ultimately replace them. These technical rules became known as the Structural Eurocodes.

5) In 1990, after consulting their respective member states, the CEC transferred the work of further development, issue and updating of the Structural Eurocodes to CEN, and the EFTA secretariat agreed to support the CEN work.

6) CEN Technical Committee CEN/TC 250 is responsible for all Structural Eurocodes.

Eurocode programme

7) Work is in hand on the following Structural Eurocodes, each generally consisting of a number of parts:

EN 1991	Eurocode 1: Basis of design and 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 alloy structures

8) Separate subcommittees have been formed by CEN/TC250 for the various Eurocodes listed above.

9) This Part of ENV 1991 is being published as European Prestandard ENV 1991-4.

10) This prestandard is intended for experimental application and for the submission of comments, and a future development is intended to cover greater eccentricities and silos with internal ties.

11) After approximately two years CEN members will be invited to submit formal comments to be taken into account in determining future actions.

12) Meanwhile feedback and comments on this prestandard should be sent to the secretariat of CEN/TC250/SC1 at the following address:

SNV/SIA (until end May 1995) Selnaustrasse 16	SIS(from June 1995) Box 3295
CH-8039 ZÜRICH	S-103 66
SWITZERLAND	STOCKHOLM
	SWEDEN

or to your national standards organization.

National Application Documents (NAD's)

13) In view of the responsibilities of authorities in member countries for safety, health and other matters covered by the essential requirements of the Construction Products Directive (CPD), certain safety elements in this ENV have been assigned indicative values which are identified by ("boxed values"). The authorities in each member country are expected to review the "boxed values" and <u>may</u> substitute alternative definitive values for these safety elements for use in national application.

14) Some of the supporting European or International standards may not be available by the time this Prestandard is issued. It is therefore anticipated that a National Application Document (NAD) giving an substitute definitive values for safety elements, referencing compatible supporting standards and providing guidance on the national application of this Prestandard, will be issued by each member country or its Standards Organization.

15) It is intended that this Prestandard is used in conjunction with the NAD valid in the country where the building or civil engineering works is located.

16) The scope of ENV 1991 is defined in clause **1.1.1** and the scope of this part of ENV 1991 is defined in **1.1.2**. Additional parts of ENV 1991 which are planned are indicated in **1.1.3**.

17) This Part is complemented by a number of informative annexes.

Contents

Section 1. General

1.1 Scope

1.1.1 Scope of ENV 1991 — Eurocode 1

1)P ENV 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 ENV 1992-1999.

2) It may also be used as a basis for the design of structures not covered in ENV 1992-1999 and where other materials or other structural design actions are involved.

3) ENV 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.

4) ENV 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.

5) ENV 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 ENV 1991-4 Actions on silos and tanks

1)P This part provides general principles and actions for the structural design of tanks and silos including some geotechnical aspects and shall be used in conjunction with ENV 1991-1: Basis of Design, other parts of ENV 1991 and ENV 1992-1999.

2) This part may also be used as a basis for the design of structures not covered in ENV 1992-1999 and where other materials or other structural design actions are involved.

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

— The silo cross section shapes are limited to those shown in Figure 1.2;

— Filling involves only negligible inertia effects and impact loads;

— The maximum particle diameter of the stored material is not greater than $0,3d_c$.

NOTE When particles are large compared to the silo wall thickness the load shall be applied as single forces.

— The stored material is free-flowing;

— The eccentricity e_0 of the stored material due to filling is less than $0,25d_c$ (Figure 1.2);

— The eccentricity e_0 of the centre of the outlet is less than $0,25d_c$;
and no part of the outlet is at a distance greater than $0,3d_c$ from the centre plane of silos with plane flow or the centre line of other silos (Figure 1.2).

— Where discharge devices are used (for example, feeders or internal flow tubes), material flow is smooth and central within the eccentricity limits given above.

— The transition is on a single horizontal plane.

— The following geometrical limitations apply:

$h/d_c < 10$

$h < 100$ m

$d_c < 50$ m

— Each silo is designed for a defined range of particulate material properties.

4) The design rules from tanks apply only to tanks storing liquids at normal atmospheric pressure.

5) ENV 1991-4 shall be used in conjunction with ENV 1991-1 and other parts of ENV 1991.

1.1.3 Further Parts of ENV 1991

1) Further parts of ENV 1991 which, at present, are being prepared or are planned are given in **1.2**.

1.2 Normative references

This European Prestandard incorporates by dated or undated reference, provisions from other standards. These normative references are cited in the appropriate places in the text and publications listed hereafter.

ISO 3898 1987, *Basis of design for structures*

Notations. General symbols.

NOTE The following European Prestandards which are published or in preparation are cited at the appropriate places in the text and publications listed hereafter.

ENV 1991-1, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-1-1, *Basis of design.*

ENV 1991-2-1, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-1-2.1, *Densities, self-weight and imposed loads.*

ENV 1991-2-2, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-2-2.2, *Actions on structures exposed to fire.*

ENV 1991-2-4, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-4-2.4, *Wind loads.*

ENV 1991-2-5, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-5-2.5, *Thermal actions.*

ENV 1991-2-6, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-6-2.6, *Loads and deformations imposed during execution.*

ENV 1991-2-7, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-2-7-2.7, *Accidental actions.*

ENV 1991-3, *Eurocode 1: Basis of design and actions on structures.*

ENV 1991-3-3, *Traffic loads on bridges.*

ENV 1991-5, *Eurocode 1: Basis of design and action on structures.*

ENV 1991-5-5, *Actions induced by cranes and machinery.*

ENV 1992, *Eurocode 2: Design of concrete structures.*

ENV 1993, *Eurocode 3: Design of steel structures.*

ENV 1994, *Eurocode 4: Design of composite steel and concrete structures.*

ENV 1995, *Eurocode 5: Design of timber structures.*

ENV 1996, *Eurocode 6: Design of masonry structures.*

ENV 1997, *Eurocode 7: Geotechnical design.*

ENV 1998, *Eurocode 8: Earthquake resistant design of structures.*

ENV 1999, *Eurocode 9: Design of aluminium alloy structures.*

1.3 Distinction between principles and application rules

1) Depending on the character of the individual clauses, 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 brackets eg. as this clause.

1.4 Definitions

For the purposes of this prestandard, a basic list of definitions is provided in ENV 1991-1, "Basis of design" and the additional definitions given below are specific to this part.

1.4.1
equivalent surface

level surface giving the same volume of stored material as the actual surface (Figure 1.2)

1.4.2
flat bottom

a flat silo bottom or a silo bottom with inclined walls where $\alpha \leqslant 20°$

1.4.3
flow pattern

the form of flowing material in the silo when flow is well established (Figure 1.1). The silo is close to its maximum filling condition

1.4.4
fluidised material

a stored material injected with air, which significantly changes the behaviour of the stored material

1.4.5
free flowing material

a material with a low cohesion

1.4.6
funnel flow (or **core flow)** (Figure 1.1)

a flow pattern in which a channel of flowing material develops within a confined zone above the outlet, and the material adjacent to the wall near the outlet remains stationary. The flow channel can intersect the vertical walled section or extend to the surface of the stored material

1.4.7
homogenizing silo

a silo containing a fluidised material

1.4.8
hopper

a silo bottom with inclined walls where $\alpha > 20°$

1.4.9
internal flow (Figure 1.1)

a funnel flow pattern in which the flow channel extends to the surface of the stored material

1.4.10
kick load

a local load that occurs at the transition during discharge

1.4.11
low cohesion

a material sample has low cohesion if the cohesion is less than 4kPa when the sample is preconsolidated to 100kPa. (A method for determining cohesion is given in Annex B)

1.4.12
mass flow

(Figure 1.1). A flow pattern in which all the stored particles are mobilised during discharge

1.4.13
patch load

a local load taken to act over a specified zone on any part of a silo wall

1.4.14
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

1.4.15 silo

Containment structure used to store particulate materials (i.e. bunkers, bins, and silos).

1.4.15.1
slender silo

a silo where $h/d_c \geqslant 1.5$

1.4.15.2
squat silo

a silo where $h/d_c < 1.5$

1.4.15.3
thin walled circular silo

a silo with a circular cross section, no stiffeners and where $d_c/t > 200$

1.4.16
tank

containment structure used to store liquids

1.4.17
transition

the intersection of the hopper and the vertical walled section

1.4.18
vertical walled section

the part of a silo or a tank with vertical walls

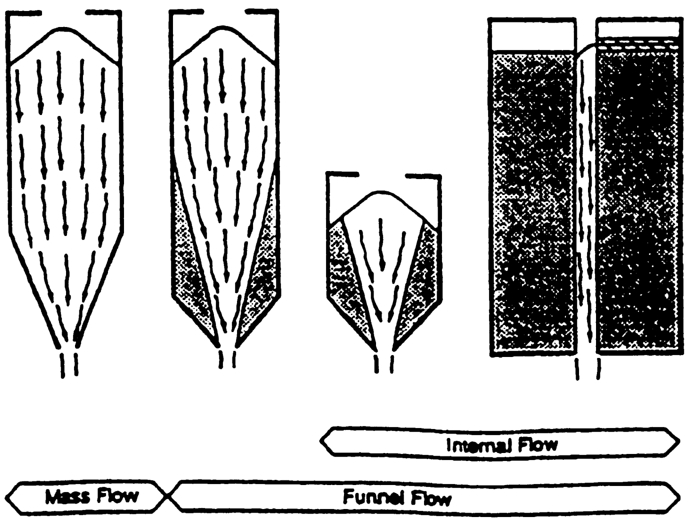

Figure 1.1 — Flow patterns

1.5 Notations

1) For the purpose of this prestandard, the following symbols apply.

NOTE The notation used is based on ISO 3839:1987.

2) A basic list of notations is provided in ENV 1991-1, "Basis of design" and the additional notations below are specific to this Part.

Latin upper case letters

A	cross-sectional area of vertical walled section
C	wall load magnifier
C_0	maximum wall load magnifier
C_b	bottom load magnifier
C_h	horizontal load magnifier
C_w	wall frictional traction magnifier
C_z	Janssen coefficient
F_p	total horizontal force due to patch load on thin walled circular silo
K_s	design value of horizontal/vertical pressure ratio
$K_{s,m}$	mean value of horizonal/vertical pressure ratio
P_w	resulting vertical load per unit perimeter of the vertical walled section
U	internal perimeter of the vertical walled section

Latin lower case letters

d_c	characteristic cross-section dimension (Figure 1.2)
e	the larger of e_i and e_o
e_i	eccentricity due to filling (Figure 1.2)
e_o	eccentricity of the centre of the outlet (Figure 1.2)
h	distance from outlet to equivalent surface (Figure 1.2)
h_1,h_2	parameters used in the determination of vertical pressures in squat silos
l_h	hopper wall length (Figure 5.3)
p	hydrostatic pressure
p_h	horizontal pressure due to stored material
p_{he}	horizontal pressure during discharge (Figure 1.2)
$p_{he,s}$	horizontal pressure during discharge calcuated using the simplified method
p_{hf}	horizontal pressure after filling
$p_{hf,s}$	horizontal pressure after filling calculated using the simplied method
p_{h0}	horizontal pressure after filling at the base of the vertical walled section
p_n,p_{ni}	pressure normal to inclined hopper wall, where i = 1, 2 and 3
p_p	patch pressure
$p_{p,sq}$	patch pressure in sqat silos
p_{ps}	patch pressure (thin walled circular silos)
p_s	kick pressure
p_t	hopper frictional traction (Figure 1.2)
p_v	vertical pressure due to stored material (Figure 1.2)
p_{ve}	vertical pressure during discharge
p_{vi}	vertical pressure components used to determine the vertical pressure in squat silos, i = 1, 2, 3
p_{vf}	vertical pressure after filling

$p_{vf,sq}$ vertical pressure after filling in squat silos
p_{v0} vertical pressure after filling at the base of the vertical walled section
p_w wall frictional pressure on the vertical section (Figure 1.2)
p_{we} wall frictional pressure during discharge
$p_{we,s}$ wall frictional pressure during discharge calculated using the simplified method
p_{wf} wall frictional pressure after filling
$p_{wf,s}$ wall frictional pressure after filling calculated using the simplified method
s dimensions of the zone affected by the patch load ($s = 0{,}2d_c$)
t wall thickness (Figure 1.2)
w width of a rectangular silo
x parameter used to calculate hopper loads
z depth below the equivalent surface at maximum filling
z_0 parameter used to calculate loads

Greek lower case

α mean angle of inclination of hopper wall measured from the horizontal (Figure 1.2)
β patch load magnifier
γ bulk weight density of liquid or stored material
γ_1 bulk weight density of fluidised stored material
θ circumferential angular coordinate
μ design value of coefficient of wall friction for pressure calculation
μ_m mean value of coefficient of wall friction for pressure calculation
φ effective angle of internal friction
φ_w angle of hopper wall friction for flow evaluation

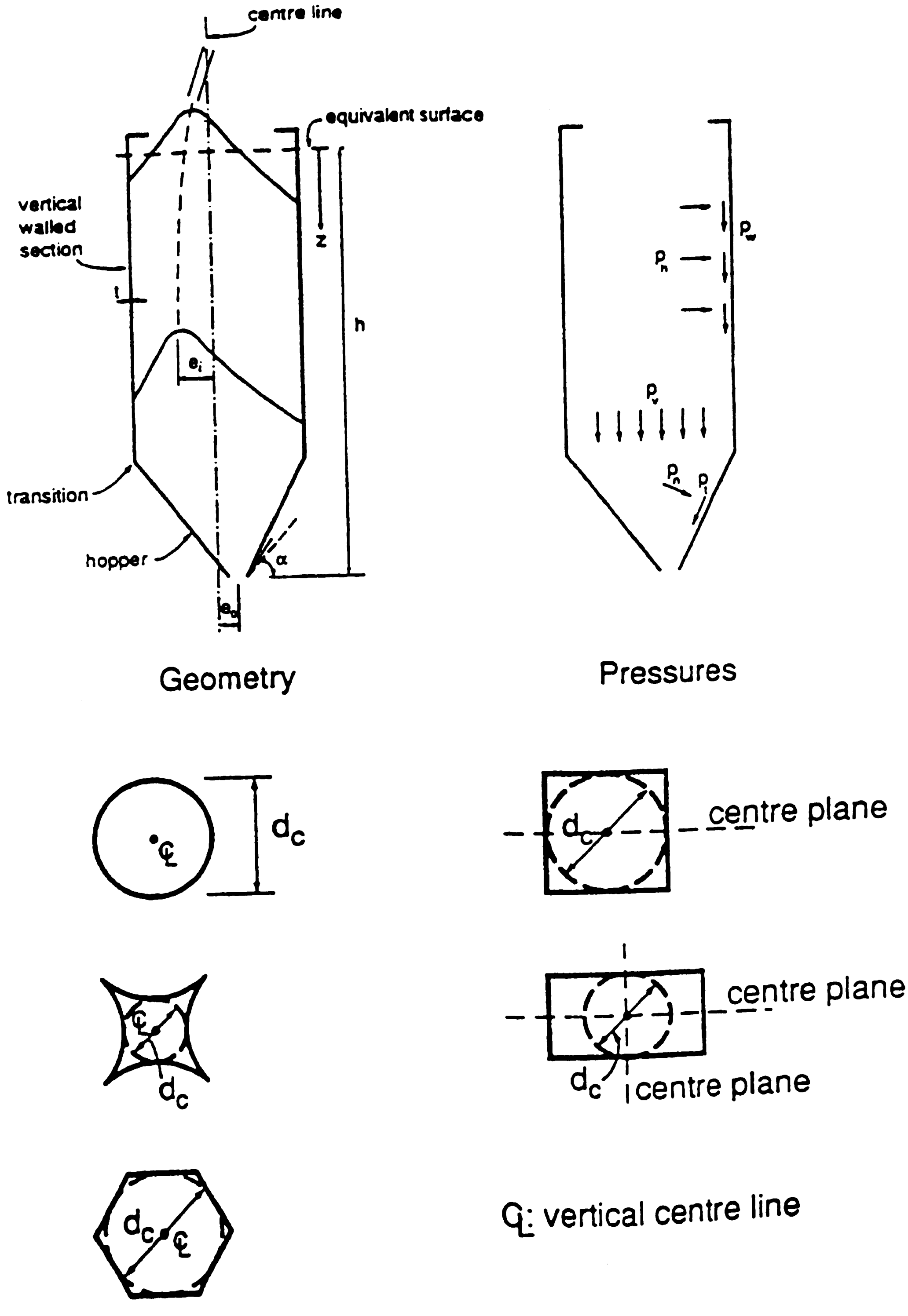

Figure 1.2 — Silo forms showing dimensions and pressure notation

Section 2. Classification of actions

1)P Loads due to stored materials are classified as variable actions, see ENV 1991-1.

2)P Loads in tanks are classified as variable actions, see ENV 1991-1.

3)P Patch loads during the filling and discharging processes of silos are classified as free actions.

4)P Loads due to dust explosions shall be classified as an accidental action.

Section 3. Design situations

1)P The general format given in ENV 1991-1 for design procedures is applicable.

NOTE This does not mean that clauses and values specified for buildings in ENV 1991-1 may be applied to silos and tanks.

2)P Selected design situations shall be considered and critical load cases identified. For each critical load case the design values of the effects of actions in combination shall be determined.

3)P The combination rules depend on the verification under consideration and shall be identified in accordance with ENV 1991-1, "Basis of design" and in accordance with Annex A.

4) The arrangement of actions on silos and tanks for load cases in a particular design situation are indicated below.

5)P Prefabricated silos shall be designed for actions due to handling, transport and erection.

6) Loads arising from the maximum possible filling shall be considered.

7) Load patterns for filling and discharge can be used at the ultimate and serviceability limit states.

8) The following accidental actions and situations shall be considered where appropriate:

- — actions due to explosions;
- — actions due to vehicle impact;
- — seismic actions;
- — fire design situations.

9) Tanks and silos may be used to store liquids or particulate materials which may cause explosions. Some of the materials which may lead to dust explosions are listed in Table 7.1.

10) The potential damage from dust explosions should be limited or avoided by appropriate choice of one or more of the following:

- — incorporating sufficient pressure relief area;
- — designing the structure to resist the explosion pressure.

11) The explosion pressure in a silo without adequate relief area may be as high as $1 N/mm^2$.

12) Prevention of dust explosions should be considered during design by appropriate choice of one or more of the following:

- — prescribing proper maintenance and cleaning routines;
- — avoiding ignition by the safe selection of electronic equipment;
- — careful use of welding equipment.

13) Cracking shall be limited to prevent water penetration when designing silos for water sensitive materials at the serviceability limit state.

14) The effects of fatigue shall be considered in silos or tanks that are subjected to an average of more than one load cycle a day. One load cycle is equal to a single filling and emptying. The effects of fatigue shall also be considered in silos affected by vibrating machinery.

15)P The actions from adjoining structures shall be considered.

Section 4. Representation of actions

1)P The structural form of the silo shall be selected to give low sensitivity to load deviations.

2)P Loads due to particulate materials shall be calculated for filing and for discharge. The magnitude and distribution of the design loads depend on the silo structure, the stored material properties and the flow patterns which arise during the process of emptying.

3) The inherent variability of stored materials and simplifications in the load models lead to differences between actual silo loads and loads given by the design rules in section 5. For example, the distribution of discharge pressures varies around the wall as a function of time and no accurate prediction of the mean pressure or its variance is possible at this time.

4) Simplified rules for the prediction of flow patterns (Figure 5.1) may be used for the calculation of actions in silos.

5) Simplified rules for the prediction of flow patterns (Figure 5.1) should not be used for the design of silos for flow.

Section 5. Loads on silos due to particulate materials

5.1 General

1) Loads due to particulate materials depend on:

— the range of particulate material properties;

— the variation in the surface friction conditions;

— the geometry of the silo;

— the methods of filling and discharge.

2) The flow pattern (mass flow or funnel flow) should be determined from Figure 5.1.

3) For the determination of the flow pattern, the angle of wall friction may be obtained either by testing as described in **5.5.2** or by using the approximate values of coefficient of wall friction given in Table 7.1 and shall be calculated as follows:

$$\phi_w = \arctan\mu_m \qquad (5.1)$$

4) Characteristic values for the filling and discharge loads are prescribed for the following types of silo:

— slender silos;

— squat silos;

— homogenizing silos and silos with a high filling velocity.

5) Any support given to the silo wall by the stiffness of the particulate material may be ignored in load calculations. This means that interaction of wall deformation and load from the stored material may be ignored.

5.2 Slender silos

1) Detailed rules for the calculation of filling loads are given in **5.2.1** and for discharge loads in **5.2.2**. Simplified rules for filling and discharge are given in **5.2.3**.

2)P General equations for the calculation of silo wall loads are given in **5.2.1**. They shall be used as a basis for the calculation of the following design loads:

— filling loads on vertical walled sections (**5.2.1**);

— filling loads on flat bottoms (**5.2.1**);

— filling loads on hoppers (**5.2.1**);

— discharge loads on vertical walled sections (**5.2.2**);

— discharge loads on flat bottoms and hoppers (**5.2.2**).

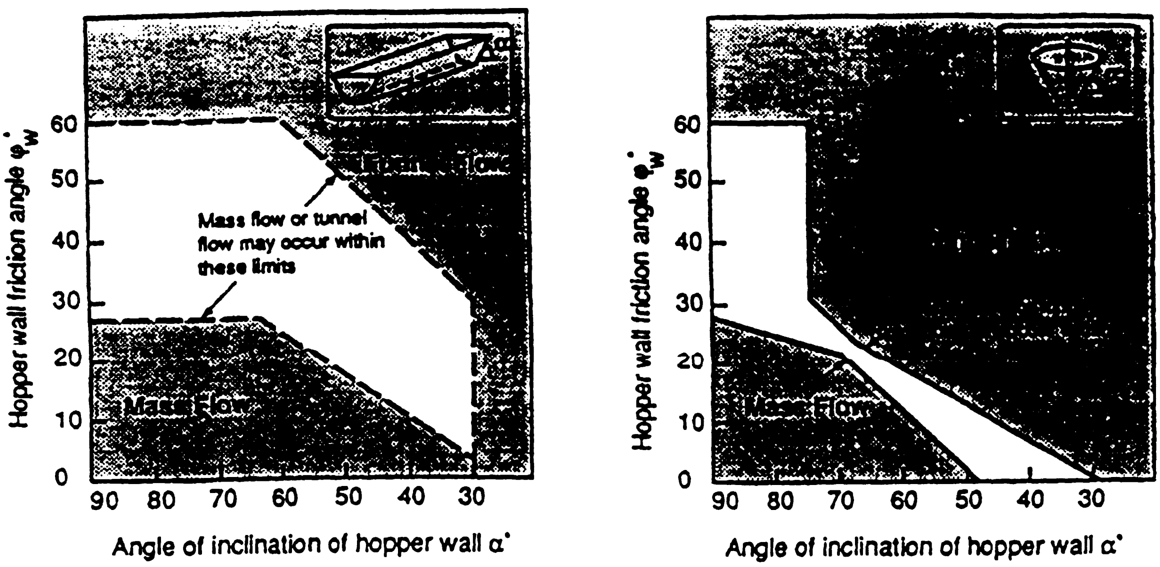

Figure 5.1 — Limit between mass flow and funnel flow for conical and wedge-shaped hoppers

5.2.1 Filling loads

1)P After filling, the values of wall frictional pressure $p_{wf,}$ horizontal pressure p_{hf} and vertical pressure p_v at any depth shall be taken as:

$$p_{wf}(z) = \gamma \frac{A}{U} C_z(z) \qquad (5.2)$$

$$p_{hf}(z) = \frac{\gamma A}{\mu U} C_z(z) \qquad (5.3)$$

$$p_v(z) = \frac{\gamma A}{K_s \mu U} C_z(z) \qquad (5.4)$$

where:

$$C_z(z) = 1 - e^{(-z/z_0)} \qquad (5.5)$$

$$z_0 = \frac{A}{K_s \mu U} \qquad (5.6)$$

where:

γ is the weight density

μ is the wall friction coefficient

K_s is the horizontal/vertical pressure ratio

z is the depth

U is the internal perimeter

2)P The resulting vertical force in the wall p_w (z) per unit length of perimeter acting at any depth z is:

$$P_w(z) = \int_0^z p_{wf}(z) dz = \gamma \frac{A}{U} [z - z_0 C_z(z)] \qquad (5.7)$$

3) Methods for determining the particulate material properties weight density, the wall friction and the pressure ratio are given in section 5.7.

5.2.1.1 *Vertical walled section*

1) The filling load is composed of a fixed load and a free load, called a patch load.

2)P The fixed load shall be calculated from expressions (5.2) and (5.3).

3) The patch pressure P_p shall be considered to act on any part of the silo wall and is taken as:

$P_p = 0{,}2\beta\ p_{hf}$ (5.8)

with:

$\beta = 1 + 4\ e_1/d_c$ (5.9)

where:

e_l and d_c are shown in Figure 1.2.

4) For concrete silos, silos with stiffeners and silos with non circular cross-section shapes, the patch pressure shall be taken to act on two opposite square areas with side length s (Figure 5.2), equal to:

$s = 0{,}2d_c$ (5.10)

5) In many silos a simplified approach can be used to apply the patch load. The most unfavourable load arrangement can be designed for by applying the patch at the mid-height of the silo and using the percentage increase in the wall stresses at that level to increase the wall stresses throughout the silo.

6) For thin walled circular silos the patch pressure shall be taken to act over a height s, but to extend from a maximum outward pressure on one side of p_p to an inward pressure p_p on the opposite side (Figure 5.2). The variation shall be taken as:

$$p_{ps} = p_p \cos\theta \tag{5.11}$$

where:

θ is given in Figure 5.2.

7) The total horizontal force F_p due to the patch load on unstiffened steel silos is given by:

$$F_p = \frac{\pi}{2}\, s\, d_c\, p_p \tag{5.12}$$

8) A simplified method can be used for applying the patch load to thin walled circular silos. The patch load may be taken to act at a depth z_o below the equivalent surface, or at the mid-height of the vertical walled section, whichever gives the higher position of the load.

5.2.1.2 *Flat bottoms*

1) Vertical loads acting on fiat or shallow silo bottoms (inclinations $\alpha \leqslant 20°$) shall be calculated as follows:

$$p_{vt} = C_b\, p_v \tag{5.13}$$

where:

p_v is calculated using expression (5.4)

C_b is a bottom load magnifier to account for the uneven load distribution calculated using expression (5.14)

$$C_b = 1{,}2 \tag{5.14}$$

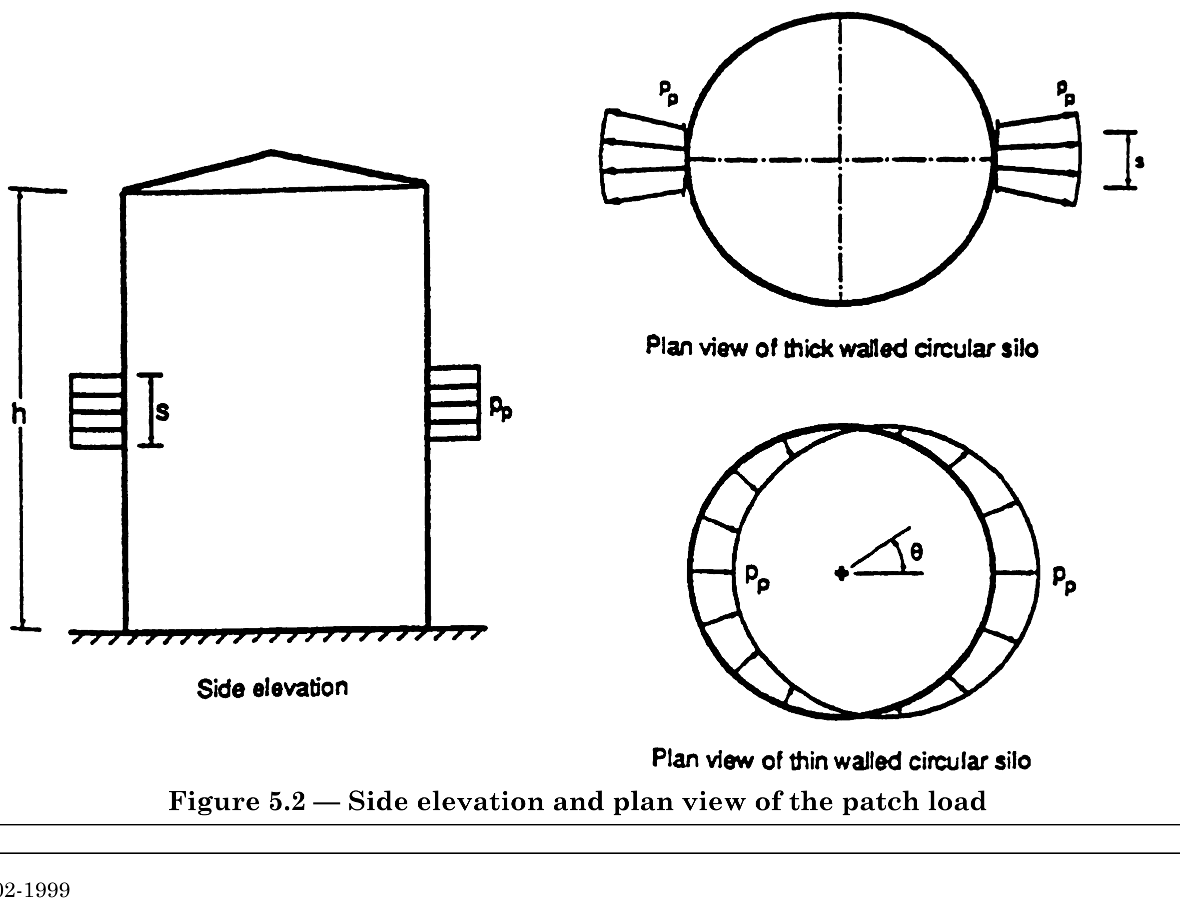

Figure 5.2 — Side elevation and plan view of the patch load

5.2.1.3 *Hoppers*

1)P When $\alpha > 20°$ (see Figure 5.3) the pressure normal to the inclined hopper wall p_n is calculated as follows:

$$p_n = p_{n3} + p_{n2} + (p_{n1} - p_{n2})\frac{x}{l_h} \quad (5.15)$$

$$p_{n1} = p_{v0}(C_b \cos^2\alpha + \sin^2\alpha) \quad (5.16)$$

$$p_{n2} = C_b p_{v0} \cos^2\alpha \quad (5.17)$$

$$p_{n3} = 3{,}0 \frac{A}{U} \frac{\gamma K_s}{\sqrt{\mu}} \sin^2\alpha \quad (5.18)$$

where:

x is a length between 0 and l_h (see Figure 5.3)

p_{n1} and p_{n2} are pressure due to hopper filling

p_{n3} is the pressure due to the vertical pressure in the stored material directly above transition.

C_b is the bottom load magnifier taken from expression (5.14)

p_{v0} is the vertical pressure acting at the transition calculated using expression (5.4)

2)P The value of the wall frictional pressure $p_{t,}$ is given by:

$$p_t = p_n \mu \quad (5.19)$$

where:

p_n is calculated from expression (5.15)

3) For silo design the vertical component of the tensile force at the top of the hopper may be required (for example, for the design of silo supports or a ring beam at the transition level). The vertical component shall be determined from force equilibrium incorporating a vertical surcharge $C_b p_{v0}$ calculated at the transition level and the weight of the hopper contents (Figure 5.3).

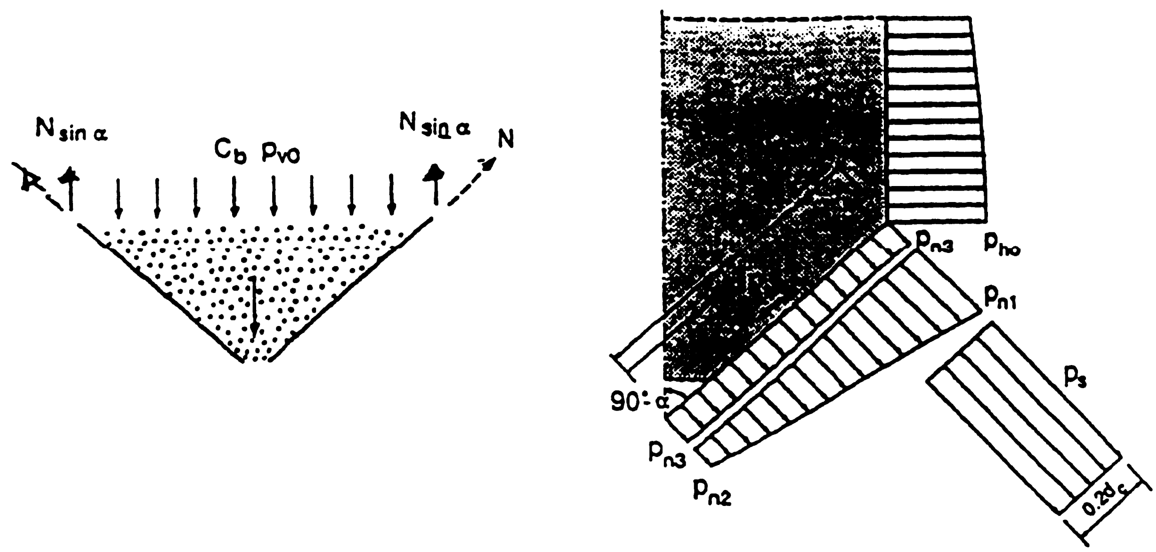

Figure 5.3 — Hopper loads and tensile force at the top of the hopper

5.2.2 Discharge loads

5.2.2.1 *Vertical walled section*

1)P The discharge loads are composed of a fixed load and a free load, called a patch load.

2) The fixed loads p_{we}, p_{he} are obtained as follows

$$p_{we} = C_w p_{wf} \quad (5.20)$$

$$p_{he} = C_h\, p_{hf} \quad (5.21)$$

where:

C_w and C_h are load magnifiers according to expressions (5.22) and (5.23).

For silos unloaded from the top (no flow):

$$C_w = C_h = 1{,}0 \quad (5.22)$$

In other slender silos the wall pressure magnifier and the horizontal load magnifier are:

$$C_w = 1{,}1 \text{ and } C_h = C_0 \text{ (see } \mathbf{7.1}\text{)} \quad (5.23)$$

3) The magnitude of the discharge patch pressure p_p is:

$$p_p = 0{,}2\beta p_{he} \quad (5.24)$$

where:

p_{he} is calculated from expression (5.21).

β depends on the greater of the filling and discharge eccentricities and is:

$$\beta = 1 + 4e/d_c \quad (5.25)$$

4) The calculation of patch loads for discharge may be carried out using the guidance given for patch loads for filling [**5.2.1.1** 4) to 8)]

5.2.2.2 *Flat bottom and hopper*

1) For funnel flow silos, the discharge loads on bottoms and hoppers may be calculated using the guidance for filling loads (**5.2.1.2** and **5.2.1.3**).

2) For mass flow silos, an additional fixed normal pressure, the kick load p_s (see Figure 5.3) is applied, over an inclined distance of $0{,}2d_c$ along the hopper wall and around the perimeter.

$$p_s = 2\, p_{h0} \quad (5.26)$$

where:

p_{h0} is the horizontal filling pressure at the transition.

5.2.2.3 *Simplified method for filling and discharge*

1) For silos, where d_c is less than 5m a simplified method for considering filling and discharge processes may be applied. In this procedure, the patch loads according to **5.2.1** and **5.2.2** may be adjusted by increasing the horizontal pressures.

2) For concrete silos, silos with stiffeners and silos with non circular cross-sections shapes the increased horizontal pressures for filling ($p_{hf,s}$) and discharge ($p_{he,s}$) are:

$$p_{hf,s} = p_{hf}\,(1 + 0{,}2\beta) \quad (5.27)$$

$$p_{he,s} = p_{he}\,(1 + 0{,}2\beta) \quad (5.28)$$

where:

p_{hf} is calculated from expression (5.3)

p_{he} is calculated from expression (5.21)

β is calcuated from expressions (5.9) or (5.25)

3) For thin walled circular silos, the increased horizontal pressures for filling $p_{hf,s}$ and discharge $p_{he,s}$ and the increased vertical pressure for filling $p_{wf,s}$ and discharge $p_{we,s}$ are:

$$p_{hf,s} = p_{hf} (1 + 0{,}1\beta) \quad (5.29)$$

$$p_{he,s} = p_{he} (1 + 0{,}1\beta) \quad (5.30)$$

$$p_{wf,s} = p_{wf} (1 + 0{,}2\beta) \quad (5.31)$$

$$p_{we,s} = p_{we} (1 + 0{,}2\beta) \quad (5.32)$$

where:

$p_{hf,s}$ is calculated from expression (5.3)

p_{he} is calculated from expression (5.21)

$p_{wf,s}$ is calculated from expression (5.2)

p_{we} is calculated from expression (5.20)

β is calculated from expressions (5.9) or (5.25)

5.3 Squat silos

1) Wall loads in squat silos should be calculated as for slender silos (see **5.2**) with the modifications for the load magnifiers, the patch pressure, the horizontal pressures, and the bottom loads.

2) The modifications concerning the load magnifiers C_h and C_w and the patch pressure are:

For silos where:

$h/d_c \leqslant 1{,}0$

$$C_w = C_h = 1{,}0, \text{ and } p_{p,sq} = O \quad (5.33)$$

For silos where:

$1{,}0 < h/d_c < 1{,}5$

$$C_w = 1{,}0 + 0{,}2(h/d_c - 1{,}0) \quad (5.34)$$

and

$$C_h = 1{,}0 + 2\ (C_0 - 1{,}0)\ (h/d_c - 1{,}0) \quad (5.35)$$

and

$$p_{p,sq} = 2p_p(h/d_c - 1{,}0) \quad (5.36)$$

where:

p_p is determined from (**5.2.1.1**) and (**5.2.2.1**)

3) The modifications shown for lateral pressure is shown in Figure 5.4. The lateral pressure p_h at the point at which the upper surface of the stored material meets the silo wall may be reduced to zero. Below this point, a linear pressure variation may be assumed (Figure 4.4), calculated using in K_s = 1.0, until this linear pressure meets the pressure determined from equation 5.3 or equation 5.21 as appropriate.

4) The vertical pressures $p_{vf,sq}$ during filling and discharge acting on the flat bottom is:

$$p_{vf,\ sq} = C_b\ (p_{v1} + (p_{v2} - p_{v3})\ (1{,}5\ D - h)/(1{,}5\ D - h_1) \quad (5.37)$$

where:

p_{v1} is obtained from expression (5.4) with $z = h$

p_{v2} is obtained from $p_{v2} = \gamma\, h_2$

p_{v3} is obtained from expression (5.4) and $z = h_1$(see Figure 5.4)

lowest point of the wall not in contact with the stored material **(**Figure 5.4**)**.

C_b is calculated from expression (5.14)

5) Hopper loads during filling shall be calculated using expression (5.15)

6) Hopper loads during discharge shall be calculated using the guidance given in **5.2.2.2** for flatt bottoms and hoppers.

5.4 Homogenizing silos and silos with a high filling velocity

1)P Homogenizing silos and silos with a high filling velocity shall be designed for the following load cases:

— The stored material fluidised.

— The stored material not fluidised.

— The stored material not fluidised.

2)P In silos storing powders where the velocity of the rising surface of the stored material exceeds 10 m/h it is assumed that the stored material is fluidised.

3)P The pressure on the silo walls *p* from fiuidised materials shall be calculated as follows:

$$p = \gamma_1 z \tag{5.38}$$

where:

γ_1 is the fluidised density.

4) The fluidised density of powders γ_1 may be taken as equal to:

$$\gamma_1 = 0,8\ \gamma \tag{5.39}$$

where:

γ is the bulk weight density of the powder determined from section 7.

5)P Design loads when the stored material is not fluidised shall be calculated for for slender silos according to section 5.2 and for squat silos according to section 5.3.

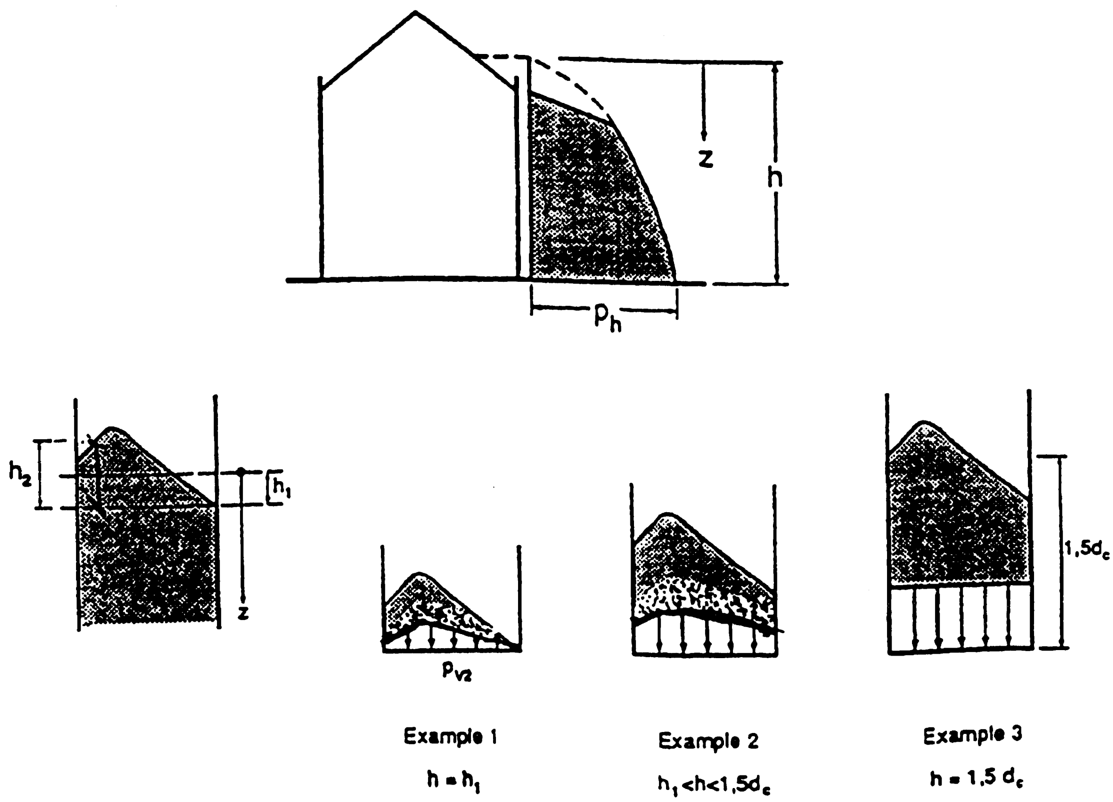

Figure 5.4 — Wall loads and flat bottom loads in squat silos

Section 6. Loads on tanks from liquids

6.1 General

1) Loads due to liquids should be calculated after considering:

— a defined range of liquids to be stored in the tank

— the geometry of the tank

— the maximum possible depth of liquid in the tank

2) The characteristic value of pressure p is:

$$p(z) = \gamma z \quad (6.1)$$

where:

z is the depth

γ is the density of the liquid

6.2 Liquid properties

1) Densities are given in ENV 1992-2-1, Densities, self weight and imposed loads.

Section 7. Material properties

7.1 Particulate material properties

1) Particulate material properties shall be determined using either the simplified approach presented in **7.2** or by testing as described in **7.3**. The maximum load magnifier C_0 is given in Table 7.1 or may be assessed from **7.4**.

7.2 Simplified approach

1) The material properties are defined in Table 7.1 Values given for γ are upper bound values whereas values of μ_m and $K_{s,m}$ are mean values.

2) To account for the inherent variability of particulate material properties and to obtain values that represent extremes of the material properties, the values of μ_m and $K_{s,m}$ should be altered by the conversion factors 0,9 and 1,15. Thus in calculating maximum loads the following combinations are used:

Max p_h for $K_s = 1,15K_{s,m}$ and $\mu = 0,9\mu_m$ (7.1)

Max p_v for $K_s = 0,9K_{s,m}$ and $\mu = 0,9\mu_m$ (7.2)

Max p_w for $K_s = 1,15K_{s,m}$ and $\mu = 1,15\mu_m$ (7.3)

NOTE For shell structures minimum (support) loads may be the unfavourable loads

7.3 Testing particulate materials

1)P Testing shall be carried out on representative samples of the particulate material. The mean value for each material property shall be determined making proper allowance for variations in secondary parameters such as composition, grading, moisture content, temperature, age, electrical charge due to handling and production method.

2)P The mean test values shall be adjusted by conversion factors to derive extreme values. The conversion factors shall be selected to allow for variability of the material properties over the silo life and for sampling inaccuracies.

3)P The conversion factors for a material property shall be adjusted if the effect of one of the secondary parameters accounts for more than 75 % of the margin introduced for the material property by the conversion factors.

7.3.1 Bulk weight density γ

1) The bulk weight density should be determined at a stress level corresponding to the maximum vertical pressure in the silo. The vertical pressure p_{vt} in the silo may be assessed using expression (5.4).

2) A test method for the measurement of bulk weight density is described in Annex B.

3) The conversion factor should be not less than 1,15.

7.3.2 Coefficient of wall friction μ_m

1) Two values μ_m should be measured. One shall be used for the determination of flow patterns and the other for the calculation of wall loads.

2) Tests to determine μ_m for the evaluation of flow patterns should be carried out at a low stress level corresponding to the stress level found during flow in the lower part of the hopper.

3) Tests to determine μ_m for the calculation of loads should be carried out at a stress level corresponding to the maximum horizontal pressure p_{hf} in the vertical part of the silo. p_{hf} may be assessed by using expression (5.3)

4) Test methods for the measurement of the two values of μ_m are described in Annex B.

5) The conversion factors shall not be less than 1,15 for the upper bound value or greater than 0,9 for the lower bound value.

7.3.3 Horizontal to vertical pressure ratio $K_{s,m}$

1) The horizontal to vertical pressure ratio $K_{s,m}$ shall be determined at a vertical stress level corresponding to the maximum vertical pressure in the silo. The test specimen shall be confined laterally. The vertical pressure may be assessed by using expression (5.4).

2) A test method is given in Annex B.

3) An alternative test method based on the measurement of the internal angle of friction is also given.

4) The conversion factors shall not be less than 1,15 for the upper bound value or greater than 0,9 for the lower bound value.

7.4 Maximum load magnifier

1) P The load magnifier C accounts for a number of phenomena occurring during discharge of the silo. The magnitude of the load magnifier increases with increasing material strength.

2) An appropriate laboratory test method for the parameter C has not yet been developed. The load magnifiers are based on experience and apply to silos with conventional filling and discharge systems and built to standard engineering tolerances.

3) For materials not listed in Table 7.1, the maximum wall load magnifier may be obtained using:

For $\varphi \leqslant 30°$ $C = 1{,}35$, and

For $\varphi > 30°$,

$$C = 1{,}35 + 0{,}02\,(\varphi - 30°) \qquad (7.4)$$

where:

φ is measured in degrees.

4) A test method to determine φ is given in Annex B.

5) Appropriate load magnifiers for specific silos with specified stored materials can be estimated based on full scale tests performed with such silos.

Table 7.1 — Particulate material properties

Particulate material	Density[3] γ[kN/m^3]	pressure ratio ($K_{s,m}$)	Coefficient of wall friction, μ_m		Maximum load magnifier C_0
			Steel[4]	Concrete	
barley[1]	8,5	0,55	0,35	0,45	1,35
cement	16,0	0,50	0,40	0,50	1,40
cement clinker	18,0	0,45	0,45	0,55	1,40
dry sand[2]	16,0	0,45	0,40	0,50	1,40
flour[1]	7,0	0,40	0,30	0,40	1,45
fly ash[2]	14,0	0,45	0,45	0,55	1,45
maize[1]	8,5	0,50	0,30	0,40	1,40
sugar[1]	9,5	0,50	0,45	0,55	1,40
wheat[1]	9,0	0,55	0,30	0,40	1,30
coal[12]	10,0	0,50	0,45	0,55	1,45

NOTE 1 Dust explosions may occur with this material.
NOTE 2 Care should be taken because of the possible range of material properties.
NOTE 3 Densities are given for the calculation of loads and should not be used for volume calculations. Densities given in Section 2 “Densities of building materials and stored materials” of ENV 1991-2-1 may be used for volume calculations.
NOTE 4 Not applicable to corrugated walls.

Annex A (Informative)
Basis of design — supplementary clauses to ENV 1991-1 for silos and tanks

NOTE This Annex is intended, at a later stage, to be incorporated into ENV 1991-1 "Basis of design".

A1 General

1) In principle the general format given in ENV 1991-1 for design procedures is applicable. However silos and tanks are different to many other structures because they may be subjected to the full design loads from particulate materials or liquids for most of their life.

2) This annex provides supplementary guidance applicable to silos or tanks regarding partial factors on actions (γ factors) and on combinations on silos and tanks with other actions; and the relevant Ψ factors.

3) Thermal actions include climatic effects and the effects of hot materials. Design situations that shall be considered include:

— Hot material filled into a partly filled silo or tank. The effects of heated air above the stored material shall be considered;

— Resistance to silo wall contraction from the stored material during cooling.

4) Determination of the effect of differential settlements of batteries of silo or tank cells should be based on the worst combination of full and empty cells.

A2 Ultimate limit state

A2.1 *Partial factors*

1) The values given in Table 9.2 of ENV 1991-1 "Basis of design" may be used for the design of silos and tanks.

2) If the maximum depth of liquid and the density of the heaviest stored liquid are will defined, the value of the partial coefficient γ may be reduced from 1,50 to 1,35.

A2.2 Ψ *factors*

1) The combination factors Ψ for silo loads and tank loads and combination factors with other actions are given in Table A1.

Table A1 — Ψ factors for silo loads and tank loads

Action	Ψ_0	Ψ_1	Ψ_2
Silos loads due to particulate materials	1,0	0,9	0,8
Tank loads due to liquids	1,0	0,9	0,8
Imposed loads Imposed deformation	0,7	0,5	0,3
Snow loads	0,6[1]	0,2[1]	0
Wind loads	0,6[1]	0,5[1]	0
Temperature	0,6[1]	0,5[1]	0
NOTE 1 Values applicable except for some geographical regions where modification may be required			

Annex B (informative) Test methods for particulate material properties

B1 Object

This annex describes test methods for the determination of the stored material parameters introduced in ENV 1991-4.

B2 Field of application

1) The test methods may be used for a specific silo design where the stored material is not listed in Table 7.1 or as an alternative to the simplified values given in Table 7.1. Reference stresses in the tests are either vertical or horizontal and they shall be representative of the stored material stresses after filling at the silo transition.

2) The test methods may also be used for the preparation of general values of material properties. Tests to determine general values shall be carried out, where applicable, at the following reference stress levels:

100 kPa to represent the vertical silo pressure (**B8**, **B9** and **B10**)

50 kPa to represent the horizontal silo pressure (**B7.2**)

B4 Notation

For the purpose of this annex the following notation applies:

c	cohesion
F_1	shear force (Figure B1)
$K_{s,m0}$	horizontal/vertical pressure ratio for smooth wall conditions
σ_r	reference stress
φ_c	angle of internal friction measured for a consolidated test specimen
τ_{fi}	maximum shear stress measured in a shear test specimen, i = 1,2

B5 Definitions

For the purpose of this annex the following definitions apply.

B5.1
secondary parameter

parameters that may influence stored material properties. Secondary parameters include material composition, grading, moisture content, temperature, age, electrical charge due to handling and production method. For the determination of general values at reference stresses as mentioned in **B2**, variations in these stress levels shall be considered a secondary parameter

B5.2
sampling

the selection of representative samples of stored material or silo wall material

B5.3
reference stress

stress levels at which the measurements of stored material properties are carried out. The reference stress is selected to correspond to the stress level in the silo after filling

B6 Sampling and preparation of samples

1) Testing shall be carried out on representative samples of the particulate material. The mean value for each material property shall be determined making proper allowance for variation of secondary parameters.

2) The following method of sample preparation shall be used for the tests described in **B7.2**, **B8**, **B9.1** and **B10**:

— The sample shall be poured into the test box, without vibration or other compacting forces and the reference stress σ_r applied. A top plate shall be rotated backwards and forwards three times through an angle of 10 degrees to consolidate the sample (Figure B1).

3) The mean test values shall be adjusted by conversion factors to derive extreme values. The conversion factors shall be selected to allow for the influence of secondary parameters, the variability of the material properties over the silo life, and for sampling inaccurancies.

4) The conversion factors for a material property shall be adjusted if the effect of one secondary parameter accounts for more than 75 % of the margin introduced for the material property by the conversion factor.

B7 Wall friction

Two parameters shall be used:

— Angle of wall friction φ_w for the evaluation of flow;

— Coefficient of wall friction μ_m for the determination of pressures.

B7.1 ***Angle of wall friction φ_w for the evaluation of flow***

B7.1.1 *Principle of the test*

A sample of the particulate material is sheared along a surface representing the hopper wall, and the friction force at the sheared surface is measured. The reference pressure is kept low to simulate the low pressures occuring during discharge near the outlet of the silo.

B7.1.2 *Apparatus and test procedure*

The test may be carried out using the apparatus described in **B7.2** and in accordance with the test procedure given in "International Standard Shear Testing Technique", Report of the European Federation of Chemical Engineering, EFCE, Working Party on the Mechanics of Particulate Solids, The Institution of Chemical Engineers, 1989 (or revisions).

B7.2 ***Coefficient of wall friction μ_m for the determination of pressures***

B7.2.1 *Principle of the test*

A sample of the particulate material is sheared along a surface representing the silo wall (a sample with corrugation in the case of corrugated steel silos) and the friction force at the sheared surface is measured.

B7.2.2 *Apparatus*

The test apparatus is shown in Figure B1. The diameter of the box shall be at least 40 times the maximum particle size and the compacted height H of the sample shall be between 0,15D and 0,20D. In the case of wall samples with irregularities such as corrugations the box size shall be selected accordingly.

B7.2.3 *Procedure*

1) The reference stress shall be equal to the horizontal silo pressure.

2) Sample preparation shall be carried out according to the guidelines given in **B6**.

3) Shearing of the sample shall be carried out at a constant rate of approximately 0,04mm/sec.

4) The friction force F_1 attained at large deformations shall be used in the calculation of the coefficient of friction (Figure B1).

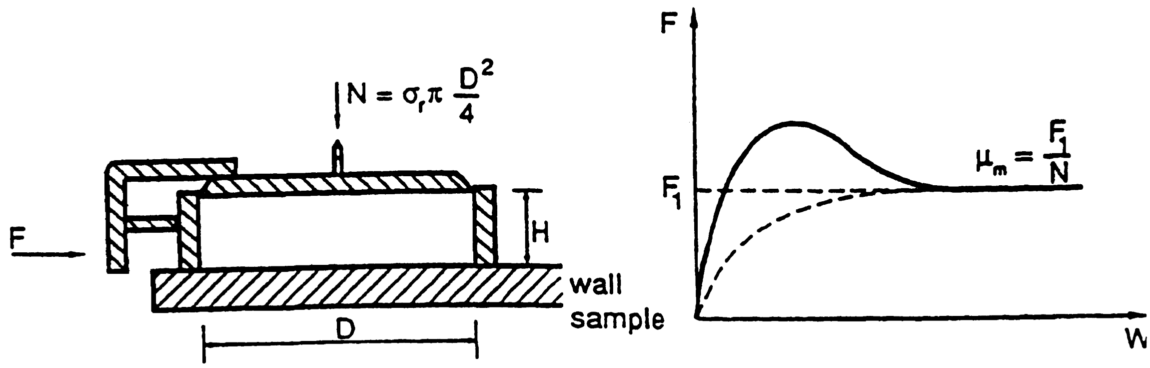

Figure B1 — Test method for determination of wall friction coefficient

B8 Consolidated bulk weight density γ

B8.1 ***Principle of the test***

The bulk weight density γ is determined from a consolidated sample of the particulate material.

B8.2 ***Apparatus***

The box shown in Figure B2 shall be used to measure the weight and volume of the material sample. The diameter D of the box shall be at least 40 times the maximum particle size and the compacted height H of the sample shall be between 0,3D and 0,4D.

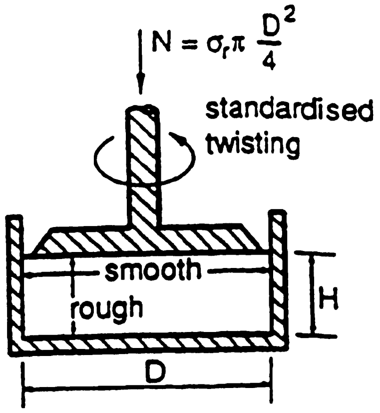

Figure B2 — Device for the determination of γ

B8.3 ***Procedure***

1) The reference stress shall be equal to the vertical silo pressure.

2) Sample preparation shall be carried out according to the guidelines given in **B6**. The bulk weight density is determined by dividing the weight of a consolidated sample of the particulate material by the bulk volume.

B9 Horizontal to vertical pressure ratio $K_{s,m}$

B9.1 ***Direct measurement***

B9.1.1 *Principle of the test*

A vertical pressure is applied to a sample constrained against horizontal deformation. The resulting horizontal and vertical stresses are measured and the coefficient $K_{s,m0}$ determined.

NOTE The magnitude of the coefficient $K_{s,m0}$ is influenced by the direction of the principal stresses in the test sample. The horizontal and vertical stresses are approximately principal stresses in the test sample whereas they may not be in the silo.

B9.1.2 *Apparatus*

The geometry of the test apparatus is similar to the apparatus described in **B8** for the measurement of bulk weight density γ (Figure B3). To measure the horizontal stress, it is necessary to have a separate bottom plate.

B9.1.3 *Procedure*

1) The reference stress shall be equal to the vertical silo pressure.

2) Sample preparation shall be carried out according to the guidelines given in **B6**.

3) The relationship between the horizontal and vertical load increments, from which $K_{s,mo}$ is calculated, is determined as indicated in Figure B3.

$K_{s,m}$ shall be taken as $K_{s,m} = 1,1\ K_{s,m0}$

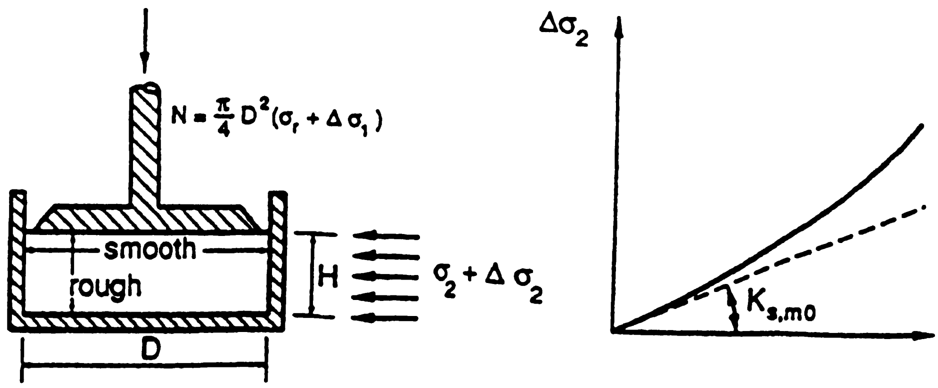

Figure B3 — Test method for determining $K_{s,mo}$

B9.2 ***Indirect measurement***

A value of $K_{s,m}$ appropriate for filling and storing conditions is:

$$K_{s,m} = 1{,}1\ (1 - \sin\varphi) \quad \text{(B.1)}$$

φ is the measured angle of internal friction which may be determined from either of the methods described in **B10** or in a triaxial test apparatus.

B10 Strength parameters, *c*, φ_c and φ

B10.1 ***Principle of the test***

The strength of a stored material sample may be determined from shear box tests. Three parameters c, φ_c and φ are used to define the stored material strength after silo filling.

B10.2 ***Apparatus***

The test apparatus consists of a cylindrical shear box, as shown in Figure B4. The shear box diameter, D, shall be at least 40 times the maximum particle size and the height H between 0,3D and 0,4D.

B10.3 ***Procedure***

1) The reference stress σ_r shall be equal to the vertical silo pressure. Sample preparation shall be carried out according to the guidelines given in **B6**.

2) The maximum shear stress τ_f developed before a horizontal displacement of w = 0,05 D is attained shall be used to calculate the material strength parameters.

3) At least two tests shall be carried out (Table B1 and Figure B4). One sample shall be sheared when loaded at the reference stress, the other shall be sheared at half the reference stress after pre-loading to the reference stress. Stresses determined from the two tests are named in Table B1.

Table B1 — Recommended tests

Test	pre-load	test load	outcome
No. 1	σ_r	σ_r	τ_{f1}
No.2	σ_r	$0.5\sigma_r$	τ_{f2}

The stored material strength parameters c, φ_c and φ are calculated as follows:

$$\varphi = \arctan (\tau_{f1}/\sigma_r) \quad \text{(B2)}$$

$$\varphi_c = \arctan (\tau_{f1} - \tau_{f2})/0{,}5\sigma_r) \quad \text{(B3)}$$

$$c = \sigma_r (\tan \varphi - \tan \varphi_c) \quad \text{(B4)}$$

4) The strength of cohesionless materials, ($c = 0$), is described by one parameter, the angle of internal friction φ, (then is equal to φ_c).

NOTE A standard triaxial test may be used in preference to the test described above.

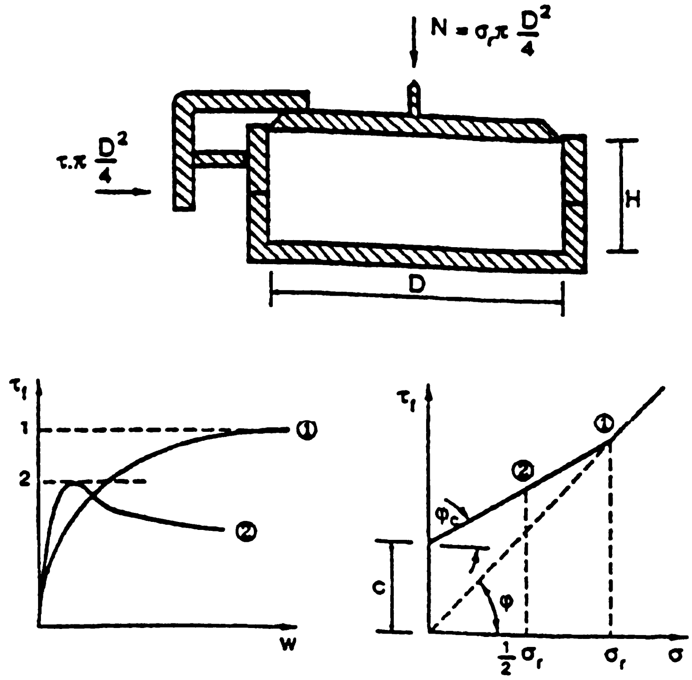

Figure B4 — Test method for determining the angles of internal friction φ and φ_c and the cohesion c at the preconsolidation level σ_r

Annex C (Informative)
Seismic Actions

NOTE This annex will be removed when this topic is covered in ENV 1998.

1) This annex gives general guidance for the design of silos for seismic actions. The design rules supplement general rules for the calculation of seismic actions on structures given in ENV 1998 and may be incorporated into ENV 1998 at a later stage.

2) The value of the earthquake acceleration for the silo structure is calculated according to ENV 1998. The silo and the particulate material may be regarded as a single rigid mass.

C2 Notation

a	horizontal acceleration due to earthquake
p_{hs}	horizontal pressure due to seismic actions

C3 Design situations

1) The following design situations shall be considered:

— horizontal accelerations and the resulting vertical loads on silo supports and foundations (**C4.1**),

— additional loads on the silo walls (**C4.2**),

— a rearrangement of the particulate material at the top of the silo. The seismic action may cause the stored material to form slip lanes endangering the roof construction and the silo walls in the upper region (Figure C1).

C4 Seismic actions

Guidance for calculation of seismic actions on silo supports and silo foundations is given in **C4.1** and guidance on silo walls is gien in **C4.2**.

C4.1 Silo supports and foundations

Seismic actions due to the weight of the silo and the particulate material may be regarding as a single force acting at the centre of gravity of the combined structure and particulate material (Figure C2).

C4.2 Silo walls

A horizontal load shall be applied to the silo walls. The load is equivalent to the mass of the particulate material multiplied by the value of the earthquake acceleration. The horizontal distribution of the pressure due to seismic actions for circular and rectangular silos is shown in Figure C3. The horizontal pressure is constant over the height of the silo except near the top of the silo where the resultant of the seismic pressure and the filling or discharge pressure shall not be less than zero.

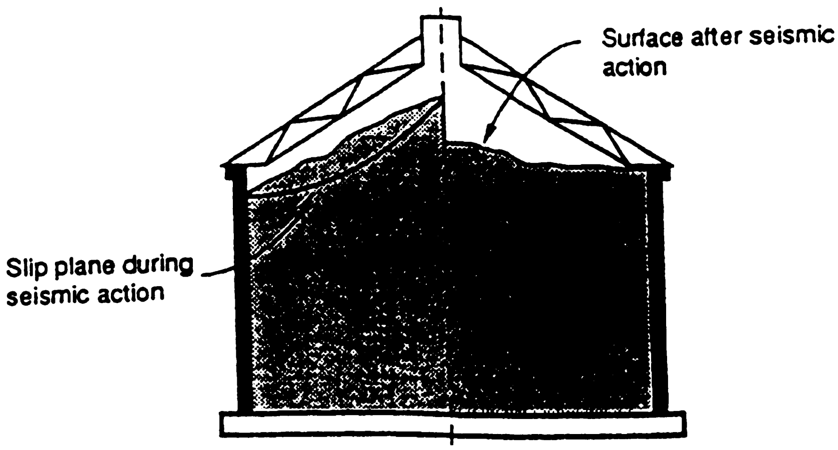

Figure C1 — Redistribution of particulate materials at the top of the silo

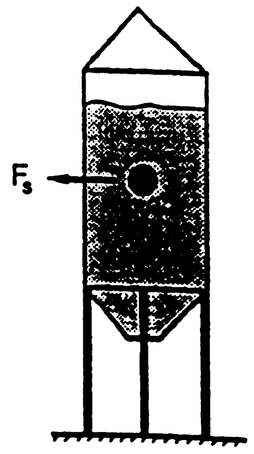

Figure C2 — Seismic action for substructure

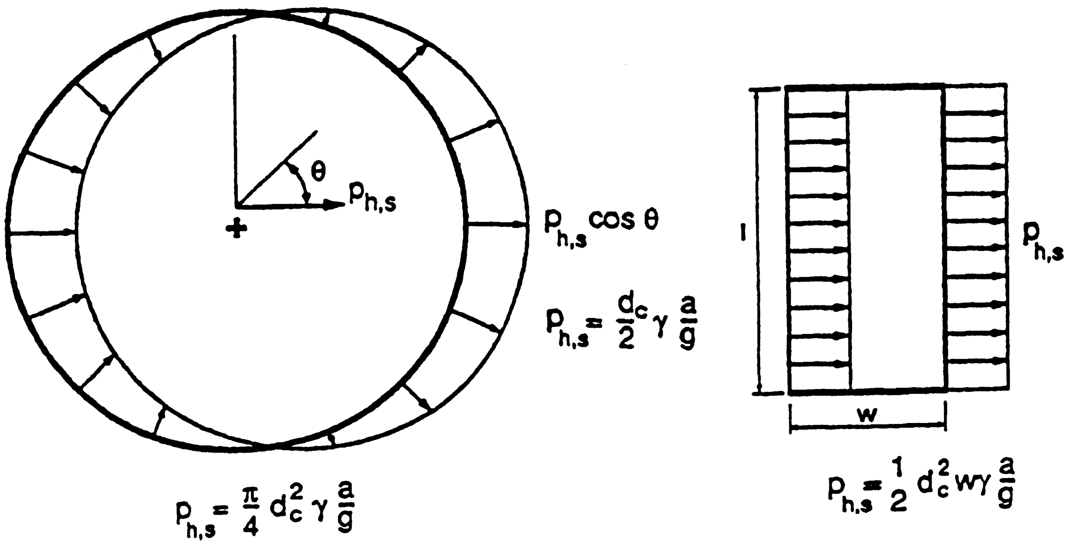

Figure C3 — Plan view of the additional horizontal pressure due to seismic actions on the vertical walled sections of silos with circular and rectangular cross section shapes

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