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Bases for design of structures — Loads due to bulk materials

Bases du calcul des constructions — Charges dues aux produits en vrac

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11697 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

Annex A of this International Standard is for information only.

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Bases for design of structures — Loads due to bulk materials

1 Scope

This International Standard deals with pressure conditions in hoppers, bunkers, bins and silos constructed using normal structural engineering materials. For the purposes of definition, the term silo is used throughout this International Standard to represent all forms of storage.

The methods given in clause 3 for the determination of loads are intended for use with the practical range of containment structures subject to the following limitations:

a) filling is a continuous process involving small inertia effects and inconsequential impact loads;

b) the maximum particle size of the ensiled bulk material is not greater than $0{,}1R$ (R = hydraulic radius);

c) where discharge devices are used (e.g. feeders, internal flow tubes, etc.), material flow is effectively continuous and centric within the eccentricity limitation given in e):

d) in bottom-discharging silos, the bulk material is free-flowing and has a low cohesion [i.e. $d_a \leqslant 1{,}0R$ (see annex A)];

e) the eccentricity e of the filling or discharge process, relative to the silo centreline, is less than $0{,}25d$ for cylindrical silos, and less than $0{,}25a$ in the case of rectangular silos;

f) the ratio of height to diameter is not greater than 10; the height is not greater than 100 m and the diameter is not greater than 50 m.

Loads determined using this International Standard consider

— a defined range of bulk material properties;

— variations in the surface friction conditions;

— the geometry of the structure;

— attachment to or loading by other structures and/or equipment;

— the methods of filling, storage and discharge.

All the above parameters shall be agreed with the client and written into all contract documents. Design of the silo shall be checked if any of the above criteria are changed.

2 Symbols and units

2.1 Symbols

a	Width of short side of a rectangular silo
A	Cross-sectional area of parallel section
c	Cohesion
C	Overpressure coefficient, load magnifier
C_z	Factor
d	Internal diameter
d_a	Material flow parameter
d_b	Maximum grain size
e	Eccentricity of discharge outlet
h	Overall height of silo
l	Length of long side of a rectangular silo

p_h Lateral pressure due to stored material

p_{he} Lateral pressure during discharge

p_{hf} Lateral wall pressure after filling

p_{h0} Lateral wall pressure in parallel section after filling

p_{ni} Pressure normal to inclined hopper wall ($i = 1, 2, 3$)

p_s Kick or switch pressure

p_t Shear stress on the hopper wall due to friction

p_v Vertical pressure due to stored material

p_w Shear stress on the vertical wall due to friction

P_w Resulting vertical force in silo wall

R Hydraulic radius of parallel section ($= A/u$)

s Length of side of square zone effected by patch load

t Wall thickness

u Cross-section perimeter of parallel section

z Vertical depth measured from effective horizontal surface

α Angle of inclination of hopper wall from horizontal

β Increasing factor for patch load

γ Weight per unit volume of stored material

γ_1 Weight per unit volume of aerated stored material

λ Horizontal/vertical pressure ratio

μ Coefficient of friction between stored material and wall ($= \tan \phi_w$)

σ_r Reference stress

σ_v Vertical stress in a shear test specimen

σ_w Preload (vertical) in a shear test specimen

σ_{w1} Actual load (vertical) in a shear test specimen

φ Effective angle of internal friction

φ_c Angle of internal friction in a test specimen

φ_w Angle of wall friction

τ_{fi} Maximum friction measured in a shear test specimen ($i = 0$ or 1)

2.2 Units

The units of measurement used in this International Standard are the International System of Units (SI).

3 Silo pressures

Load and pressures in this International Standard are nominal values substituting relevant fractiles during the design life of the structure or the permanency of the design.

3.1 Principles of silo pressure

The filling pressures of bulk materials depend mainly on the material properties and the silo geometry. However, discharge pressures are also influenced by the flow patterns which arise during the process of emptying. Therefore an assessment of material flow behaviour shall be made for each silo design.

3.1.1 Flow patterns (see figure 1)

In the assessment of bulk-material flow it is necessary to distinguish between three main flow patterns.

a) **Mass flow** [see figure 1 a)]: A flow profile in which all the stored particles are mobilized during silo discharge.

b) **Funnel flow** (or **core flow**) [see figure 1 b) to f)]: A flow profile 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 wall of the parallel section or extend to the top surface. In the latter case, the pattern is called internal flow [see figure 1 c) to e)].

c) **Expanded flow** [see figure 1 f)]: A flow profile in which mass flow develops within a steep-bottom hopper, combining with a stationary zone in an upper less-steep hopper at the bottom of the parallel section. The mass flow zone then extends up the wall of the parallel section.

Different pressure distributions are associated with each of the above flow patterns.

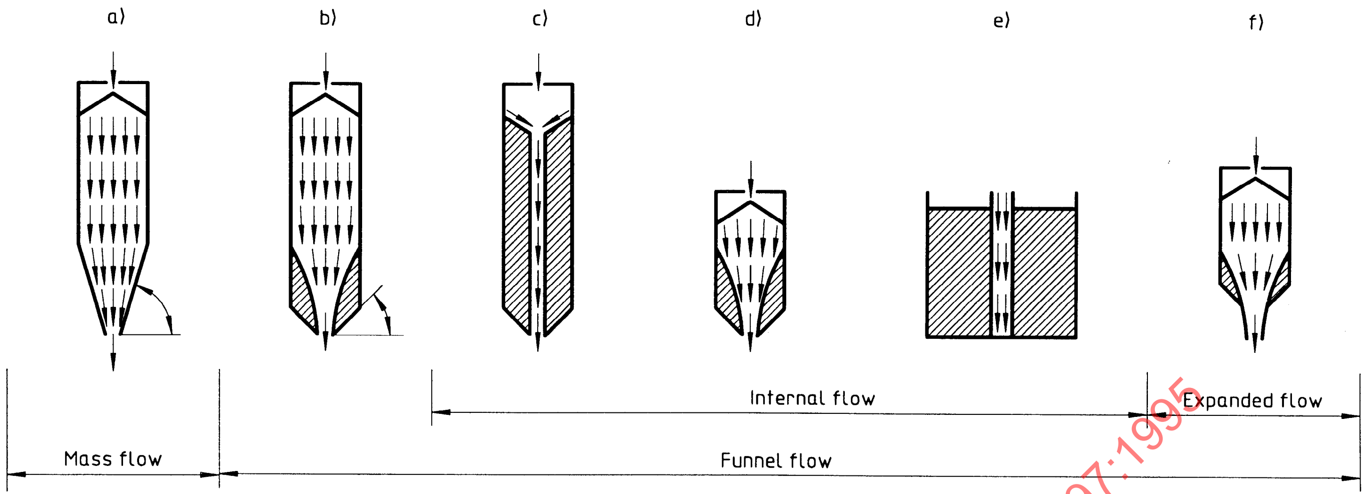

Figure 1 — Flow patterns

The conditions necessary for mass flow depend on the inclination of the hopper wall and the wall friction coefficient. They may be estimated using figure 2 for conical and axisymmetrical hoppers, and figure 3 for configurations producing plane flow. The transition regions shown in figures 2 and 3 represent conditions in which the flow pattern can change abruptly between mass and funnel flow, thereby producing unsteady flow with pressure oscillations. If such conditions cannot be avoided, the silo shall be designed for both mass flow and funnel flow.

A silo may be designed for funnel flow only if figure 2 or figure 3 establishes that this is the only possible flow pattern.

Top-unloading bins may be designed as always operating in internal flow.

3.1.2 Pressure analysis

In this International Standard, the calculation of silo pressures is based on Janssen's theory with the following assumed conditions:

a) static vertical equilibrium;

b) a uniform vertical pressure acts upon any horizontal section;

c) in cylindrical silos, the lateral pressures are symmetrically distributed around the wall circumference;

d) wall friction depends only on the lateral pressure;

e) a constant wall friction coefficient (i.e. Coulomb friction).

All the above assumptions are idealizations or simplifications.

In practice, silo pressures are known to be unsymmetrical due to the effects of segregation during filling, geometric wall imperfections and eccentric filling or discharge, even if these are nominally concentric. Pressures in silos are not only governed by static phenomena but also involve dynamic responses with probabilistic characteristics.

Eccentric filling or eccentric discharge of a silo can cause highly unsymmetrical loadings on the wall, floor and supporting elements.

Nevertheless, pressures calculated using the methods proposed in this International Standard are in good overall agreement with measurements, provided all aspects of the design which are specific to each individual silo, such as inherent material variability, etc., are considered.

During filling and storage, an elastic or active state of stress is developed within the stored mass. When a silo discharges in funnel flow, this stress state is disturbed to varying degrees over the height of the silo. In the region where the flow channel intersects the wall, a position which varies in both a vertical and horizontal plane, the stress state changes towards a passive condition with a corresponding increase in the ratio of lateral to vertical pressure. To deal with this situation, a multiplying overpressure factor C has been introduced into the pressure calculation. This factor is derived from experience and experimental measurements using different bulk materials (see clause 5). This factor also accounts for local pressure increases due to imperfections in the wall geometry, inhomogeneity of the bulk material, slip/stick properties and small discharge eccentricities.

Silo design shall consider unfavourable parameter combinations in determining the design loadings.

For the calculation of lateral and vertical pressures, the value of the vertical coordinate z is taken from a fictitious horizontal surface representing the actual mass of the stored bulk material and its assumed density. The surface level of the stored bulk solid can be changed by the actions of aeration, pneumatic filling, vibration of silo walls, or mechanical spreading of the material during filling.

In this International Standard, the calculated pressures are assumed to be continuous. In situations where particle sizes are large in comparison with the wall thickness, the need for special provisions shall be investigated.

3.2 Basic equations

The pressures at a depth z in the cylindrical section are as follows:

$$p_{\mathrm{wf}}(z) = \gamma R \times C_z(z) \qquad \ldots (1)$$

$$p_{\mathrm{hf}}(z) = \frac{\gamma R}{\mu} \times C_z(z) \qquad \ldots (2)$$

$$p_{\mathrm{vf}}(z) = \frac{\gamma R}{\lambda \mu} \times C_z(z) \qquad \ldots (3)$$

The factor C_z is given by:

$$C_z(z) = 1 - e^{(-z/z_0)} \qquad \ldots (4)$$

The depth z_0 is given by:

$$z_0 = \frac{R}{\lambda \mu} \qquad \ldots (5)$$

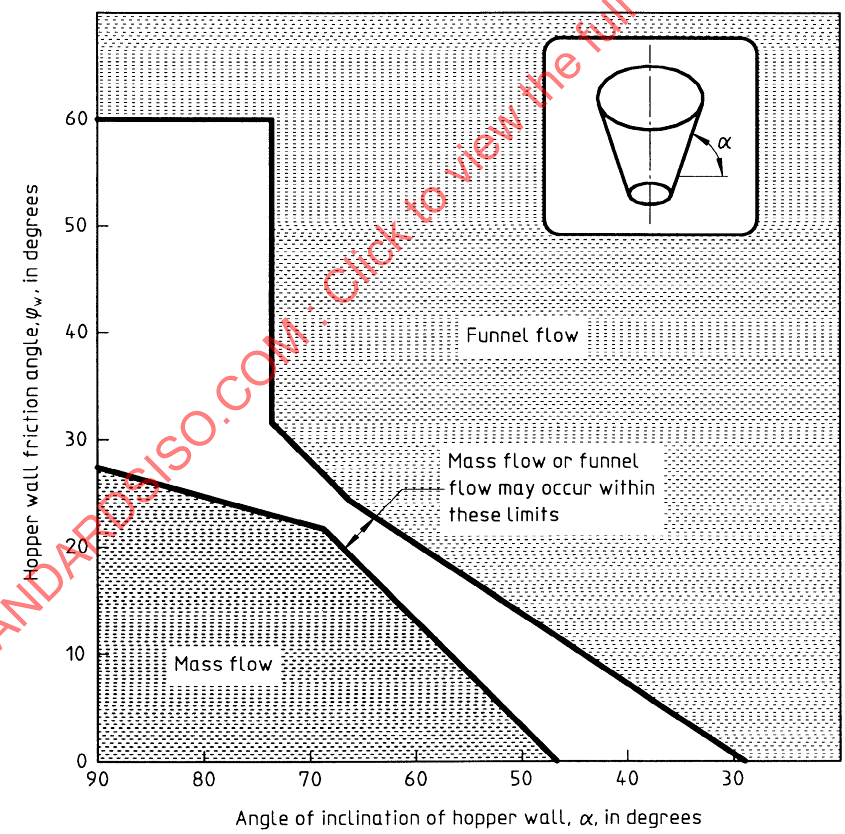

Figure 2 — Limit between mass flow and funnel flow for circular hoppers

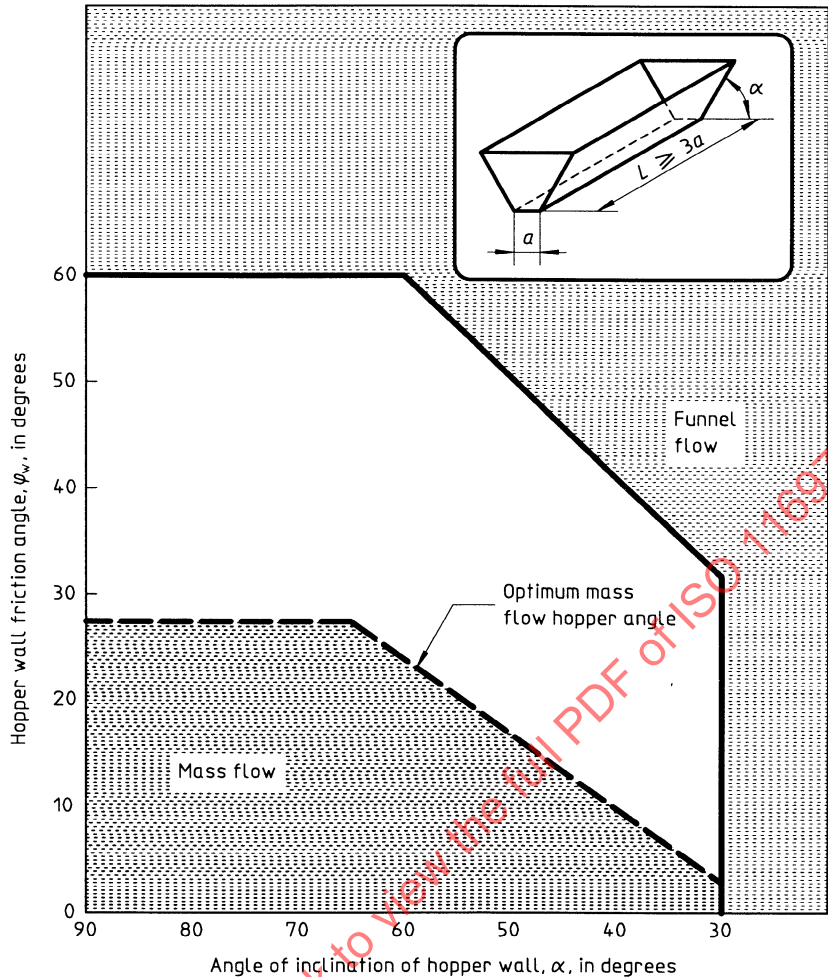

Figure 3 — Limit between mass flow and funnel flow for wedge-shaped hoppers

The friction forces p_w acting on the wall may be integrated vertically to calculate the resulting vertical force in the wall, $P_w(z)$, per unit circumference acting at the depth z, using following equation:

$$P_w(z) = \int_0^z p_{wf}(z)\,dz = \gamma[z - z_0 C_z(z)] \qquad \ldots (6)$$

The bulk materials properties γ, μ and λ are given in clause 4.

3.3 Wall pressure

Filling pressure acting on the wall of the cylindrical section are calculated directly from equations (1), (2), (4) and (5).

In silos where the flow zone intersects the wall (i.e. all flow patterns except internal flow), the design discharge pressures shall be obtained by multiplying the filling loads by an overpressure coefficient C. The value of C shall be related to the silo aspect ratio h/d:

for	$h/d \leqslant 1{,}0$	$C = 1{,}0$
for	$1{,}0 < h/d < 1{,}5$	$C = 1{,}0 + 0{,}7(h/d - 1{,}0)$
for	$h/d \geqslant 1{,}5$	$C = 1{,}35$

These values apply only to materials which conform to the classes defined in table 1. For other materials, the value of C can be calculated from equation (A.3) of annex A.

In silos having an internal flow pattern [i.e. in figure 1 c), d) and e)], the design discharge pressures shall be taken as equal to the filling and storage pressures.

3.3.1 Patch load

Unsymmetrical pressures are unavoidable even where concentric filling of axisymmetrical silos is involved, and are dependent on both the characteristics of the bulk material and the imperfections in the as-built silo geometry. Inhomogeneities and probabilistic changes within the bulk material can also contribute to fluctuations in the flow zone. For these reasons, silos should be designed to resist unsymmetrical loads, with special attention to the induced bending moments.

To account for such actions, an additional patch load of magnitude $0,2p_{he}$ shall be taken to act on any part of the silo wall over a square zone of side length $s = 0,8A/u$ (see figure 4). Any possible support given to the silo wall by the bulk material shall be ignored in this calculation.

3.3.2 Eccentric discharge

Discharge through an eccentric outlet or outlets results in an unsymmetrical pressure distribution around the circumference of the silo, inducing bending moments in the wall. It can also initiate buckling of the wall of a steel silo. Silo walls shall be designed to resist these loads.

An examination of many published pressure distributions for eccentric discharge, having their origins in both theoretical and experimental studies, has shown little consistency. The following simplification is therefore proposed for estimating the maximum pressures.

For discharge eccentricities smaller than $0,25d$ in the case of circular silos, and less than $0,25a$ for rectangular silos, the patch load (see 3.3.1) should be increased by a factor β, given in the following equation:

$$\beta = 1,0 + 4,0e/d$$

This expression does not apply to eccentricities in excess of $0,25d$.

It should be noted that where eccentricities are large (i.e. e approaches $0,5d$), lateral wall pressures during discharge, p_{he}, can approach zero on the side of the opening.

3.4 Bottom loads

Values of vertical pressures acting on flat or shallow silo bottoms under filling and discharge conditions (inclinations $\alpha \leqslant 20°$) shall be calculated using equation (3) increased by the empirical factor 1,35. This does not allow for impact loads during filling or the possibility of dynamic loads due to unreliable flow.

For vertical pressures on the floor of a squat silo, see 3.7.

3.5 Hopper loads

Theories for the calculation of pressures in silo hoppers are available in the literature, but the phenomenon is still not fully understood and agreement between different calculation methods is poor. Therefore a simple, semi-empirical method for the computation of hopper pressures is recommended.

The normal wall pressure, p_n, under filling and discharge conditions in hoppers having $\alpha \geqslant 20°$ shall be calculated as the sum of loads due to hopper filling [equation (9)] and loads resulting from the vertical surcharge directly above the transition [equations (7) and (8)]. (See figure 5.)

$$p_{n1} = 1,5p_{h0}\left(\frac{1}{\lambda}\cos^2\alpha + \sin^2\alpha\right) \quad \ldots (7)$$

$$p_{n2} = \frac{1,5}{\lambda} p_{h0} \cos^2\alpha \quad \ldots (8)$$

$$p_{n3} = 3,0 \frac{A}{U} \frac{\gamma\lambda}{\sqrt{\mu}} \sin^2\alpha \quad \ldots (9)$$

where p_{h0} is the lateral wall pressure acting on the vertical wall immediately above the hopper in the filling condition, as calculated from equation (1).

For shallow hopper angles ($\alpha < 20°$), the normal pressure p_n shall be taken as equal to the bottom loads calculated in 3.4.

The frictional tractions on the hopper wall are given by the following equation:

$$p_t = \mu p_n \quad \ldots (10)$$

where p_n is the sum of p_{n1}, p_{n2} and p_{n3} [equations (7) to (9)].

Loads resisted by silo supports shall be determined from force equilibrium using a vertical surcharge p_{vf}, acting on a horizontal surface directly above the hopper, increased by the empirical factor of 1,35.

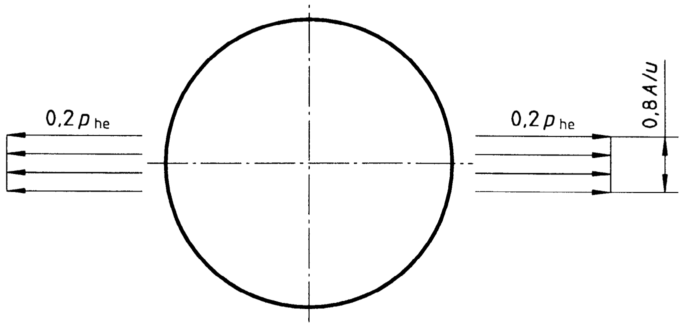

Figure 4 — Patch load

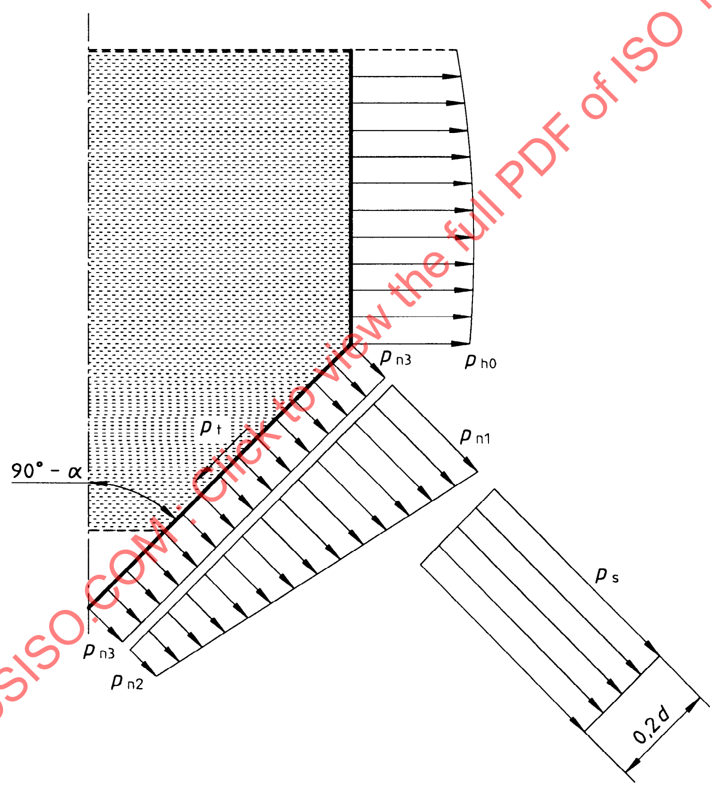

Figure 5 — Hopper loads

3.6 Kick pressure in mass-flow bins

At the transition between the vertical wall and the hopper in a mass-flow silo, the normal wall pressure during discharge becomes considerably larger than the filling pressure. This phenomenon is commonly referred to as the "switch" or "kick" pressure.[1)]

For mass-flow silos, a uniform normal pressure, p_s, extending over an inclined distance of 0,2d below the transition (see figure 5) shall be added to the pressures calculated in accordance with section 3.5.

$$p_s = 2p_{h0} \qquad \ldots (11)$$

where p_{h0} is the horizontal filling pressure in the parallel section.

1) Various methods for the calculation of the peak "switch" pressure have been proposed but for the purpose of design calculations, a simplified approach is recommended.

3.7 Squat bins

A squat silo is defined as one in which the height/diameter ratio is less than 1,5.

Where silo discharge is nominally central, no distinction is made between the filling and discharge pressures. Design wall pressures shall be calculated in accordance with the recommendations for silo filling pressures [see 3.2 equations (1) to (5)], except that:

a) 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, calculated using $\lambda = 1,0$ (see figure 6), until the pressure so calculated reaches the initial load determined from equation (2);

b) the vertical pressures acting on the silo bottom shall be calculated from equation (3) using $z = h$ at the wall and $z = 1,5d$ at the centre of the silo, but need not be taken as greater than γz.

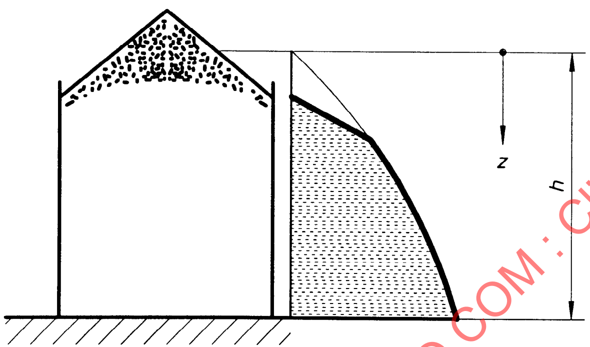

Figure 6 — Horizontal wall pressure in shallow bins

3.8 Pressure in homogenizing silos

Wall pressures generated in the storage of pneumatically blended bulk solids shall be calculated from the hydraulic pressure:

$$p_h = p_v = \gamma_1 z \quad \dots (12)$$

where γ_1 is the aerated density which, in the absence of measurements, may be taken as equal to $\gamma_1 = 0,8\gamma$ for powders.

Pressures on the silo bottom and frictional wall loads shall be calculated using equations (1) to (6), assuming that the material is not homogenized (i.e. unaerated conditions).

In silos storing powdered materials and having a filling velocity exceeding 10 m/h, it shall be assumed that aerated conditions are developed.

4 Material properties

Lateral pressure ratios shall be determined using the simplified approach presented in table 1, which is based on the concept of different classes for each material property.

Each material is represented by the parameters γ, μ and λ, values of which are found from the appropriate class, as shown in table 2.

Table 1 — Material classes

Material class	Density, γ kN/m³	Stress ratio, λ	Coefficient of wall friction, μ
1	7,5	0,3	0,3
2	8,5	0,4	0,4
3	10,0	0,5	0,5
4	13,0	0,6	0,6
5	16,0	0,75	0,75

The coefficient of wall friction given in table 1 is for smooth-walled (e.g. welded or folded steel and aluminium sheets, synthetic material, etc.) silos only. Where the silo wall is known to be rough (e.g. concrete, plaster, wood, etc.), the wall friction coefficient in table 1 may be increased by 0,1.

The values of the material parameters λ and μ defined in table 1 represent mean values; the values given for γ represent upper limits. To account for the known inherent variability of bulk material properties and to obtain values which represent reasonable extremes to which the silo may be subjected, the parameters μ and λ shall be increased by the factor 1,15 or decreased by the factor 0,9 whenever this results is a more onerous combination of structural loadings.

In calculating maximum design loads, the following combinations of the parameters λ and μ shall be considered.

For maximal value of p_h: 1,15λ and 0,9μ

For maximal value of p_v: 0,9λ and 0,9μ

For maximal value of p_w: 1,15λ and 1,15μ

Table 2 — Classification of materials

Bulk solid	Density class, γ	Stress ratio class, λ	Coefficient of wall friction class, μ
Barley	2	4	1
Cement	5	4	2
Cement clinker	5	3	2
Dry sand	5	3	2
Flour	1	2	1
Fly ash	4	3	3
Maize	2	4	1
Sugar	3	4	3
Wheat	2	4	1
Coal	3	3	3

5 Testing bulk materials

5.1 General

If the design requires a more accurate description of the material parameters or if materials other than those listed in table 1 are to be stored, appropriate values of material parameters may be obtained by testing in accordance with the following guidelines.

Testing should be carried out on representative samples of the bulk material. A 'representative sample' is defined here as one which gives a reliable average value for each material property, making proper allowance for variations in composition, grading, moisture content, temperature, age, production method, etc.

To account both for changes in the material properties over the expected life of the silo and for sampling inaccuracies, these average test values should be adjusted by conversion factors to derive maximum and minimum values.

The above approach does not cover situations where the design loads are so sensitive to variations in one of the material parameters that the effect accounts for more than 75 % of the safety margin introduced by the above conversion factors.

5.2 Unit bulk weight, γ

The unit bulk weight, γ, is defined as the mass of a quantity of particulate solid divided by its total volume and multiplied by the acceleration due to gravity $\left(g = 9{,}81 \text{ m/s}^2\right)$. The bulk density is equal to γ/g.

In measuring the bulk density, consideration should be given to the vertical pressure which will develop when the material is stored, and which may affect the bulk density. Vertical pressures may be assessed from equation (3).

A suitable test method for the measurement of bulk density is described in annex A.

The conversion factor for unit bulk weight shall not be less than 1,15.

5.3 Coefficient of wall friction, μ

The coefficient of wall friction, μ, is the ratio of shear stress against the vertical or inclined wall to the normal stress against the wall. Two values shall be considered, relating respectively to incipient movement and fully developed movement of the particulate solid against the wall.

The conditions used in a test to determine the coefficient of wall friction shall be consistent with the pressures and bulk density developing within the stored material (i.e. low pressure levels for flow assessment; high pressure levels for strength calculations). A suitable test method is described in annex A.

The conversion factor for the coefficient of wall friction shall not be less than 1,15 for the upper bound value, nor greater than 0,9 for the lower bound value.

5.4 Horizontal to vertical pressure ratio, λ

The horizontal to vertical pressure ratio, λ, is assumed to represent the filling and storing stress state in the silo in which a laterally confined state of stress is developed (i.e. silo walls are much stiffer than the stored material). The value of λ shall be determined from the following equation:

$$\lambda = 1,1(1 - \sin\varphi) \qquad \ldots (13)$$

where φ is the effective angle of internal friction.

The value of φ may be taken as the ultimate strength of an under-consolidated material sample subject to a vertical pressure representative of conditions developing within the stored material.

A suitable test method is described in annex A.

The conversion factor for λ shall not be less than 1,15 for the upper limit, nor greater than 0,9 for the lower limit.

5.5 Overpressure factor, C

An overpressure factor, C, is used in the calculation of flow pressures in silos. Its role is to account for the effects of a number of phenomena related to both flow of particulate solids and structural imperfections.

The overpressure factor adopted throughout this International Standard is given in 3.3. It applies only to the materials defined in table 1. This value is based on experience and applies to silos using conventional filling and discharge systems and built to normal engineering tolerances.

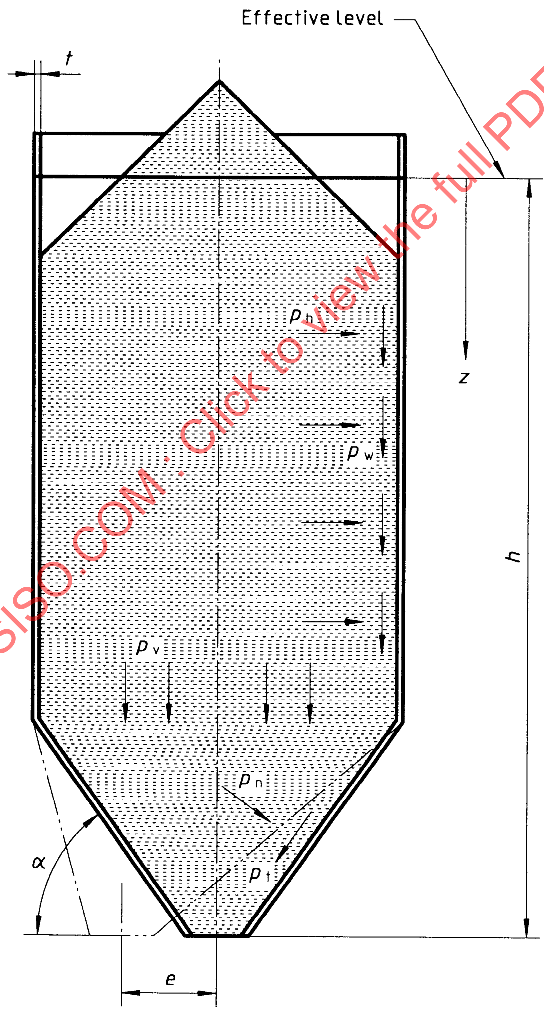

Figure 7 — Silo bin dimensions

Annex A
(informative)

Test methods

This annex describes test methods for the determination of parameters introduced in this International Standard for the calculation of loads from the storage and discharge of bulk materials.

A.1 Sampling

Samples should be representative of the materials expected to be stored with respect to such secondary parameters as composition, grading, moisture content, temperature, age, method of production, etc. However, part of the investigation should include the determination of the parameter variation as a consequence of changes in the secondary parameters.

A.2 Maximum grain, size, d_b

A.2.1 Principle

The maximum grain size should be determined from a sieve test and is defined by the size of the mesh opening which allows 95 % of the sample by weight to pass through.

The maximum grain size is introduced to limit the scope of this International Standard to situations where the concepts of continuum mechanics are valid.

A.2.2 Apparatus and test procedure

A sieve test in accordance with the appropriate International Standard should be carried out.

A.3 Material-flow parameter, d_a

A.3.1 Principle

The material-flow parameter defines the limits for free-flowing materials. The purpose is to exclude materials which are known to cause deleterious dynamic phenomena in regions of high pressure. This parameter should not be mistaken for a similar parameter which is determined at low pressure levels and is used to assess the risk of arching across the outlet zone.

A.3.2 Determination

The parameter d_a may be calculated from the following equation:

$$d_a = \frac{4c \cos\varphi_c}{\gamma(1 - \sin\varphi_c)} \qquad \text{... (A.1)}$$

where

c is the material cohesion;

φ_c is the angle of internal friction in the test specimen, preconsolidated at a stress level corresponding to the maximum vertical pressure p_v in the silo if known, or alternatively at a pressure of 100 kPa.

Test methods for the measurement of c and φ_c are described in A.9.

A.4 Angle of wall friction for evaluation of flow (see figures A.2 and A.3)

A.4.1 Principle

The test methods used here to assess material flow are based on the methods recommended by the European Federation of Chemical Engineering.

A sample of the bulk material is sheared along a surface representative of the silo wall. The normal force is kept low to reflect the low pressures occurring during discharge in the vicinity of the outlet.

A.4.2 Apparatus and test procedure

The test is carried out in accordance with the test procedure given in "International Standard Shear Testing Technique", Report of the EFCE Working Party on the Mechanics of Particulate Solids, The Institution of Chemical Engineers, 1989. A more accurate evaluation of the type of flow may be made by using the standard shear testing technique described in the same publication.

A.5 Consolidated unit bulk weight, γ

A.5.1 Principle

The unit bulk weight is an essential parameter in equations (1) to (6) for the calculation of silo pressures. For some materials, the unit bulk weight depends on the stress state of the solid, which may vary with the silo size and the method of filling. The unit bulk weight needed in this context is therefore different from unit bulk weights used in trade or other scientific characterization of materials.

The purpose of this test is therefore to measure an appropriate material density. This is achieved by weighing a sample of the bulk material and dividing this by the bulk volume measured after consolidation. The unit weight determined by this method should represent a suitable upper limit for the calculation of loads.

A.5.2 Apparatus

To determine the unit bulk weight, a cylindrical box should be used with a diameter, D, at least 40 times the maximum particle size and with a compacted height, H, between 0,30D and 0,40D (see figure A.1).

A.5.3 Procedure

The sample is poured into the cylindrical box without vibration or other compacting forces, after which a normal force N is applied producing the reference stress σ_r (the maximum value of p_v or 100 kPa, as appropriate). The top plate is then rotated back and forth three times through an angle of 10°. The unit bulk weight γ is determined from the measured weight and compacted volume of the sample.

A.6 Coefficient of wall friction, μ_r for determination of loads

A.6.1 Principle

The principle of this test is identical to that for the angle of wall friction, except that a high normal pressure is specified.

A.6.2 Apparatus

To determine the coefficient of wall friction, a shear box is used with a diameter not less than 40 times the maximum particle size and with a height H between 0,15D and 0,20D.

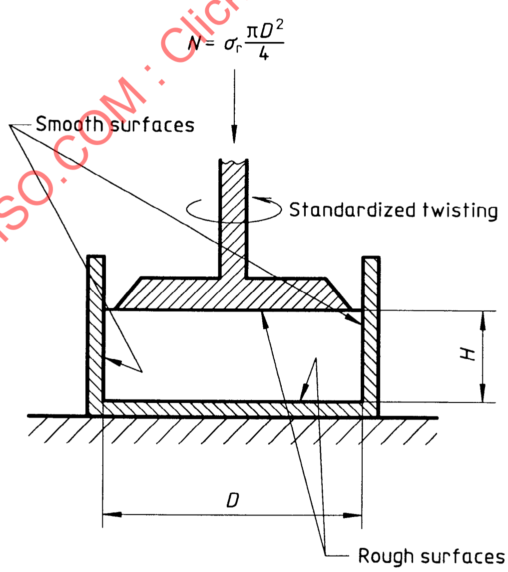

Figure A.1 — Device for the determination of γ