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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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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.

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. $d_a \leq 1,0R$ (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.

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

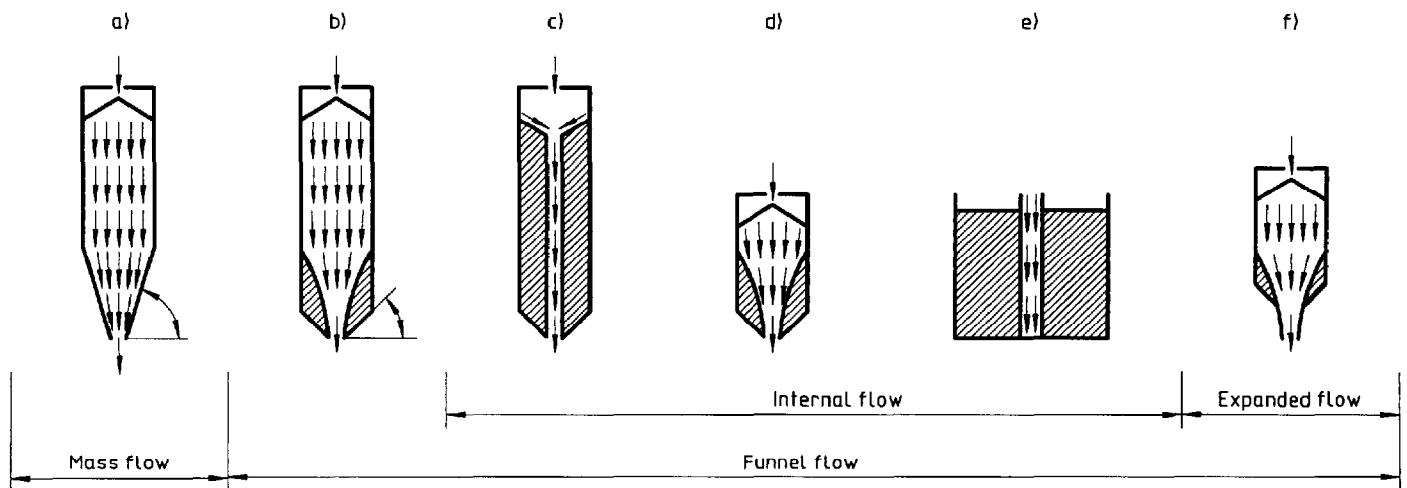


Figure 1 — Flow patterns

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, inhomogeneous