

Australian Standard[®]

Loads on bulk solids containers

This Australian Standard was prepared by Committee BD/65, Loads on Bulk Solids Containers. It was approved on behalf of the Council of Standards Australia on 30 August 1996 and published on 5 October 1996.

The following interests are represented on Committee BD/65:

Bureau of Steel Manufacturers of Australia
CSIRO, Division of Building, Construction and Engineering
Institution of Engineers Australia
Swinburne University of Technology
University of Melbourne
University of Sydney
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Loads on bulk solids containers

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PREFACE

This Standard was prepared by the Standards Australia Committee BD/65 on Loads on Bulk Solids Containers.

This Standard is based on *Guidelines for the assessment of loads on bulk solids containers* (first edition, 1986) prepared by a working party on bins and silos of the National Committee of Structural Engineering, The Institution of Engineers Australia.

The principal objective of the Standard is to provide users with nationally acceptable unified rules for the determination of loads for the design of containment structures, including bins, silos, bunkers, and dump hoppers, for the mass storage of granular bulk solids.

An amendment was approved by the Committee to take account of the 1993 publication of AS 1170.4, *Minimum design loads on structures (known as the SAA Loading Code)*, Part 4: *Earthquake loads*, and incorporate additional improvements to the clarity and intent of particular requirements, based on user comments. Other technical changes covered by the amendment are principally those initiated by comments from users of the Standard and relate to particular clauses in Sections 4, 6 and 7. The Committee recommended that, rather than issuing an amendment, a second edition of the Standard be published which incorporated the approved amendment.

Appropriate amendments to the relevant clauses in the Commentary on the Standard (AS 3774 Supplement 1) are issued concurrently with this second edition of AS 3774.

The terms 'normative' and 'informative' have been used in this Standard to define the application of the appendix to which they apply. A 'normative' appendix is an integral part of a Standard, whereas an 'informative' appendix is only for information and guidance.

Statements expressed in mandatory terms in notes to tables and figures are deemed to be requirements of this Standard.

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Australian Standard

Loads on bulk solids containers

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard specifies requirements for the determination of loads for the design of containment structures, including bins, silos, bunkers, and dump hoppers, for the mass storage of granular bulk solids.

This Standard does not apply to containers for the storage of silage or containers with parameters not complying with Section 2.

NOTE: A typical bulk solids container specification data sheet is shown in Appendix A.

1.2 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

AS

1170	Minimum design loads on structures (known as the SAA Loading Code)
1170.1	Part 1: Dead and live loads and load combinations
1170.2	Part 2: Wind loads
1170.4	Part 4: Earthquake loads
1250	The use of steel in structures (known as the SAA Steel Structures Code)
1657	Fixed platforms, walkways, stairways and ladders—Design, construction and installation

1.3 DEFINITIONS For the purpose of this Standard, the definitions below apply.

1.3.1 Angle of repose—the angle between the surface of a piled-up bulk solid and the horizontal plane.

1.3.2 Axisymmetric flow—a flow pattern formed during the discharge from a container of a bulk solid and characterized by particle trajectories that are symmetrical about the vertical axis of the container.

1.3.3 Bulk solids container—a generic name for all types of structures for containment of granular bulk solids, generally equipped with discharge outlets and capable of being emptied by gravity or by mechanical or pneumatic means.

1.3.4 Coefficient of wall friction—the ratio of the frictional traction to lateral wall pressure at any point on the container wall.

1.3.5 Coefficient of variation—the standard deviation expressed as a percentage of the mean value.

1.3.6 Cone—a conical hopper.

1.3.7 Cylinder—the vertical part of a circular container.

1.3.8 Dead zone—a zone of material that cannot be discharged by gravity.

1.3.9 Eccentric flow—a flow pattern in which the vertical centre-line of the flow channel does not coincide with the vertical centre-line of the container.

1.3.10 Effective angle of internal friction—angle between the abscissa and the tangent of the curve representing the relationship of shearing resistance to normal stress acting within a soil.

1.3.11 Effective transition—a point of intersection between the primary flow zone and the wall of a funnel flow container.

1.3.12 Expanded flow—a flow pattern combining mass flow within the hopper with funnel flow in the portion of the container above the hopper.

1.3.13 Flow factor—a parameter which depends on the ratio of the strength to the consolidation pressure in a bulk solid.

1.3.14 Flow load—the load induced by the flow of a bulk solid during discharge.

1.3.15 Funnel flow—a flow pattern in which the primary flow zone meets the container wall below the free surface (see Figure 2.2).

1.3.16 Hopper—the converging part of the container, ending in a discharge outlet. A hopper may be conical, pyramidal, wedge, chisel, or transitional in shape.

1.3.17 Initial load—the load induced during filling and storing.

1.3.18 Live storage—the difference between the total volume of the stored bulk solid and the volume occupied by the dead zone.

1.3.19 Lower characteristic value—a value chosen to correspond to a 5% probability of not being exceeded during the intended life of the structure or the permanency of the design.

1.3.20 Mass flow—a flow pattern in which the primary flow zone occupies the whole container (see Figure 2.2).

1.3.21 Pipe flow—a flow pattern in which the primary flow zone only meets the container wall at the free surface (see Figure 2.2).

NOTE: Pipe flow is also known as ‘rat holing’.

1.3.22 Planar flow—a flow pattern characterized by flow trajectories that are symmetrical about the vertical plane through the longitudinal axis of the outlet slot.

1.3.23 Pressure multiplier—a coefficient to convert the initial pressure to a flow pressure.

1.3.24 Primary flow zone—the flow zone occurring immediately after the container outlet is opened.

1.3.25 Secondary flow zone—the zone of discharge after the primary flow zone has essentially discharged. The zone is static immediately after the container outlet is opened.

1.3.26 Traction—the shear force per unit area at the interface between the bulk solid and the wall caused by the frictional drag of a bulk solid.

1.3.27 Upper characteristic value—a value chosen to correspond to a 95% probability of not being exceeded during the intended life of the structure or the permanency of the design.

1.4 NOTATION The quantity symbols used in this Standard are given in Table 1.1.

TABLE 1.1
NOTATION

Quantity symbol	Term	Unit symbol	Text reference
A_w	area of wall	m ²	Clause 6.2.3.5
A_c	cross-sectional area of the column	m ²	Clause 7.3.3
A_D	area of the discharge outlet	m ²	Clauses 6.6.1, 6.6.3
A_{str}	plan projected area of structural element	m ²	Clause 6.10.5
a	start-up acceleration of the feeder	m/s ²	Clause 6.6.3
b	container width	m	Clause 6.2.3.2, Table 2.2
C	seismic response factor for base shear	—	Clauses 7.4.1, 7.4.2
c	flow multiplier	—	Clause 6.3.1
c_c	flow geometry coefficient	—	Clauses 6.3.2.1, 6.3.2.2
c_F	coefficient of rapid filling	h	Clause 6.2.1.5, Table 6.4
c_h	hopper geometry coefficient	—	Clause 6.3.5
c_{nf}	normal wall pressure multiplier	—	Clause 6.3.2.1
c_{nT}	temperature load multiplier	—	Clause 7.3.2
c_p	Ratio of the profile wetted circumference per pitch to the nominal profile pitch	—	Clause 3.4.4
c_{qf}	traction flow multiplier	—	Clauses 6.3.3.1, 6.3.3.2
c_{sw}	pressure coefficient for swelling pressures	—	Clause 7.5
c_{vf}	vertical pressure multiplier for flow	—	Clauses 6.3.4, 6.10.2, Table 3.1
c_z	Janssen depth function	—	Clauses 6.2.1.1, 6.2.1.9, 6.2.2.1, 6.2.2.3, 6.2.3.1
c_{ze}	eccentric Janssen depth function	—	Clauses 6.4.1, 6.4.2
c_1	Janssen depth function at depth h_0 below the highest bulk solid wall contact	—	Clauses 6.2.1.2, 6.2.2.2
d_a	annular dimension	m	Table 2.2
d_c	diameter of a cylindrical container, or the largest inscribed diameter of any shape	m	Clauses 2.1.2, 2.1.6, 4.4.2, 6.2.1.8, 6.2.3.2, 6.3.2.1, 6.3.2.2, 6.4.1, 6.5.2.2, 6.5.2.3, 7.4.3.2, 7.4.3.3, Table 2.2
d_e	distance from near side eccentricity axis	m	Clause 6.5.2.3
E_C	elastic modulus of column	kPa	Clause 7.3.3
E_s	upper bound elastic modulus of bulk solid	kPa	Clauses 3.4.6, 6.2.1.8, 7.3.2
E_w	elastic modulus of the container wall	MPa	Clause 6.2.1.8
e	base of Napierian logarithms	—	Clauses 6.2.1.1, 6.2.1.2, 6.2.2.1, 6.2.3.1, 6.2.3.2, 6.4.1, 7.5
e_o	eccentricity of discharge outlet	m	Clauses 6.5.2.1, 6.5.2.2, 6.5.2.3
F_g	vertical load on outlet gate	kN	Clause 6.6.1
F_h	local concentrated load	kN	Clause 6.2.3.5
F_k	bulk solid deceleration force	kN	Clause 6.6.2
F_{str}	vertical force acting on an internal structural element in the stored solid	kN	Clause 6.10.5

(continued)

TABLE 1.1 (continued)

Quantity symbol	Term	Unit symbol	Text reference
F_w	impact force on wall	kN	Clause 6.2.1.7
ΔF	axial force reduction	kN	Clause 7.2.2
G_g	total weight of structure including contents	kN	Clause 7.4.1
g	acceleration due to gravity	m/s ²	Clauses 6.2.17, 6.3.2.3, 6.6.3
H_1	horizontal force exerted by bulk solid due to feeder operation	kN	Clause 6.6.3
h_B	height above the pneumatic floor discharge system	m	Clause 6.8.3
h_b	total effective height of stored bulk solid	m	Clauses 2.1.2, 6.3.2.1, 7.4.3.2, 7.4.3.3
h_c	height of container vertical section to highest bulk solid wall contact	m	Figure 2.6, Clause 6.2.3.3
h_h	height of the hopper from the apex to the transition	m	Clauses 6.3.5, 6.6.1
h_k	height from apex to free surface of bulk solid in hopper	m	Clause 6.6.2
h_D	height above discharge outlet	m	Clause 6.5.2.2
h_o	height of reference surface above the highest bulk solids wall contact	m	Clauses 2.2.2, 6.2.1.2, 6.2.1.3, 6.2.2.2, 6.3.5, 6.4.1
h_s	height of the filling cone or wedge	m	Clauses 2.2.2, 6.4.1
h_t	lower bound height of effective transition	m	Clause 6.3.2.2
h_1	height of fall before impact with wall	m	Clause 6.2.1.7
I	occupancy importance factor	—	Clauses 7.4.1, 7.4.3.2, 7.4.3.3
j	hopper exponent	—	Clauses 6.3.5, 6.6.1
K_{str}	translational stiffness of the whole structure	kN/m	Clause 7.4.2
k	lateral pressure ratio	—	Clause 6.2.1.1, Tables 6.1, 6.3
k_h	initial normal pressure ratio for hopper	—	Clause 6.2.3.3
k_1	lower characteristic value of lateral pressure ratio	—	Clause 6.2.3.1
k_{hf}	normal pressure ratio for hopper	—	Clauses 6.3.5, 6.3.7
k_m	mean lateral pressure ratio	—	Clause 6.2.3.6
k_u	upper characteristic value of lateral pressure ratio	—	Clauses 6.2.2.1, 6.4.1
l	container length	m	Clause 6.2.3.2, Table 2.2
l_h	length of wedge hopper	m	Clause 6.6.2
l_{str}	horizontal perimeter of structural element	m	Clause 6.10.5
l_w	length of the wall in the direction of the seismic force	m	Clause 7.4.3.3
m	mass of the individual falling lump	kg	Clause 6.2.1.7
m_1	mass of single discretely dumped volume	kg	Clause 6.2.3.5
N_a	additional compressive force	kN	Clause 7.3.3
N_j	compressive force in column j	kN	Clause 7.3.3
N_{ten}	vertical wall tension per unit circumference	kN/m	Clause 7.5
N_{zf}	vertical wall load per unit circumference during flow due to frictional traction	kN/m	Clause 6.3.3.2
N_{zi}	initial vertical wall load per unit circumference due to frictional traction	kN/m	Clauses 6.2.2.3, 6.3.3.2

(continued)

TABLE 1.1 (continued)

Quantity symbol	Term	Unit symbol	Text reference
ΔN	axial force increase in adjacent columns	kN	Clause 7.2.2
n	exponent	—	Clause 6.3.2.1
p_B	maximum blower pressure	kPa	Clause 6.8.3
p_c	maximum pressure due to pneumatic blower	kPa	Clause 6.8.3
p_{ef}	normal pressure increase due to eccentric flow	kPa	Clause 6.5.2.2
$p_{ef,max}$	maximum pressure increase due to eccentric flow	kPa	Clause 6.5.2.2
$p_{ef,red}$	normal pressure reduction due to eccentric flow	kPa	Clause 6.5.2.3
p_f	flow load	kPa	Clause 6.3.1
p_g	initial vertical pressure on a gate or feeder	kPa	Clauses 6.6.1, 6.6.3
p_i	initial load	kPa	Clause 6.3.1
p_l	local pressure	kPa	Clause 6.8.3
p_{nB}	local pressure due to pneumatic blower	kPa	Clause 6.8.3
p_{nf}	normal pressure on the vertical walls during flow	kPa	Clauses 6.3.2.1, 6.5.2.2, 6.5.2.3, 6.10.3
p_{nhf}	normal pressure on the walls of a hopper during flow	kPa	Clauses 6.3.5, 6.3.6, 6.3.7
p_{nhi}	initial normal pressure on hopper wall at a depth z_h below the transition	kPa	Clauses 6.2.3.3, 6.2.3.4, 6.2.3.6
p_{ni}	initial normal pressure	kPa	Clauses 6.2.1.1, 6.2.1.2, 6.2.1.5, 6.2.1.6, 6.2.1.8, 6.3.2.1, 6.4.1, 6.8.3
p_{niF}	maximum normal wall pressure resulting from rapid filling	kPa	Clause 6.2.1.5
$p_{ni,min}$	minimum wall pressure	kPa	Clause 6.2.1.9
$p_{ni,red}$	reduced normal wall pressure	kPa	Clause 6.2.1.8
p_{np}	normal wall pressure due to pneumatic blending	kPa	Clause 6.2.1.6
$p_{n,str}$	horizontal pressure on internal structural element	kPa	Clause 6.10.3
p_{nT}	normal wall pressure increase due to differential thermal condition	kPa	Clause 7.3.2
p_{nti}	initial normal pressure on hopper wall just below the transition	kPa	Clause 6.2.3.3
p_{nv}	additional normal pressure on hopper	kPa	Clause 6.6.2
p_{nw}	normal pressure on walls of a container due to earthquake	kPa	Clauses 7.4.3.1, 7.4.3.2, 7.4.3.3
p_q	frictional traction	kPa	Clause 7.4.3.3
p_{qb}	frictional traction exerted on the base of the container due to earthquake	kPa	Clause 7.4.3.2
p_{qf}	frictional traction between stored solid and vertical wall during flow	kPa	Clauses 6.3.3.1, 6.10.4
p_{qhf}	frictional traction on hopper walls during flow	kPa	Clause 6.3.6
p_{qhi}	initial frictional traction on hopper walls	kPa	Clause 6.2.3.4
p_{qi}	initial frictional traction between stored bulk solid and vertical wall	kPa	Clauses 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.3.3.1
p_{qie}	frictional traction between the stored solid and vertical wall of an eccentrically filled container	kPa	Clause 6.4.2

(continued)

TABLE 1.1 (continued)

Quantity symbol	Term	Unit symbol	Text reference
$p_{q, \text{str}}$	frictional traction acting on structural element	kPa	Clauses 6.10.4, 6.10.5
$p_{q, \text{sw}}$	vertical frictional traction induced by swelling	kPa	Clause 7.5
p_{qv}	additional frictional traction on hopper	kPa	Clause 6.6.2
p_{q1}	frictional traction at depth h_0 below the highest bulk solid wall contact	kPa	Clause 6.2.2.2
p_{Six}	initial horizontal shear at a distance x normal to the long wall from centre-line of container	kPa	Clause 6.2.3.2
p_{Siy}	initial horizontal shear at a distance y normal to the short wall from centre-line of container	kPa	Clause 6.2.3.2
p_{sw}	pressure due to swelling	kPa	Clause 7.5
p_v	vertical pressure on a horizontal plane	kN/m ²	Clause 7.5
p_{vbf}	vertical pressure on the structural elements of flat bottomed container	kPa	Clauses 6.3.4, 6.10.4
p_{vhf}	vertical pressure in the hopper during flow at any depth z_h below the transition	kPa	Clauses 6.3.5, 6.3.7
p_{vi}	mean initial vertical pressure on any horizontal plane	kPa	Clauses 3.4.6, 6.2.3.1, 6.2.3.2, 6.2.3.6, 6.3.4, 6.6.1
p_{vit}	mean vertical pressure in the bulk solid at the level of the transition	kPa	Clauses 6.2.3.3, 6.3.5
p_{vix}	initial pressure on the base of a flat bottomed container at distance x from centre	kPa	Clause 6.2.3.2
$p_{\text{v, str}}$	vertical pressure on internal structural element	kPa	Clauses 6.10.2, 6.10.5
p_1	Janssen pressure at depth h_0 below the highest bulk solid wall contact	kPa	Clause 6.2.1.2
q_f	rate of fill	m ³ /h	Clause 6.6.2
R_f	structural response factor	—	Clause 7.4.1
r	radius of circular container	m	Clause 7.3.2
r_c	characteristic dimension of container cross-section	m	Clauses 6.2.1.1, 6.2.1.2, 6.2.1.9, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.3.1, 6.4.1, 6.4.2, 7.5, Table 2.2
r_e	eccentricity of filling	m	Clause 6.4.1
r_1	radius of the column pitch circle	m	Clause 7.3.3
S	numerical factor for site-structure resonance	—	Clauses 7.4.1, 7.4.3.2, 7.4.3.3
s	number of columns around the container circumference	—	Clause 7.3.3
T	natural period of the structure	s	Clause 7.4.2
t	thickness of wall	m	Clauses 2.1.6, 6.2.1.8, 7.3.2
u_1	ratio	—	Clauses 7.4.3.2, 7.4.3.3
u_2	ratio	—	Clause B3
u_3	ratio	—	Clause B3
V	seismic horizontal force	kN	Clause 7.4.1
V_D	dumped volume	m ³	Clause 6.2.3.5
v_c	initial vertical velocity at discharge into the container	m/s	Clause 6.2.1.7
v_E	estimated velocity	m/s	Clauses 6.2.1.7, 6.6.2

(continued)

TABLE 1.1 (continued)

Quantity symbol	Term	Unit symbol	Text reference
v_F	filling rate	m/h	Clause 6.2.1.5
W_g	weight of the stored solid between the hopper outlet and the gate or feeder	kN	Clauses 6.6.1, 6.6.3
x	radial coordinate in a circular container	m	Clause 6.2.3.2
x_1	coordinate from the centre of the circle towards the subject column	m	Clause 7.3.3
x_2	dimension of sheeting profile	m	Figure B1
$\bar{x}$	property value (Appendix B only)	m	Clause B2
$\bar{\bar{x}}$	average property value (Appendix B only)	m	Clause B2
$x_{0.05}$	lower characteristic value (Appendix B only)	m	Clause B2
$x_{0.95}$	upper characteristic value (Appendix B only)	m	Clause B2
y	coordinate with origin at the centre of the base and normal to the short wall	m	Clause 6.2.3.2
y_1	dimension of sheeting profile	m	Figure B1
z	depth below the effective surface	m	Clauses 2.2.2, 3.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.5, 6.2.1.6, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.3.1, 6.3.4, 6.4.1, 6.10.5, 7.5, Table 6.2
z_c	vertical distance below the highest contact between the stored solid and the structure	m	Clause 6.2.1.3
z_e	height which varies around the container circumference depending on the eccentricity of filling r_e	m	Clause 6.4.1
z_g	depth of the gate below the solid effective surface, or below the cylinder to hopper transition	m	Clause 6.6.1
z_h	depth below the cylinder to hopper transition	m	Clauses 6.2.3.3, 6.2.3.6, 6.3.5, 6.6.1, 6.6.2
z_m	depth for maximum rapid filling pressure	m	Clause 6.2.1.5
z_o	characteristic depth	m	Clauses 6.2.1.1, 6.2.1.2, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.3.1, 6.4.1, 7.5, Table 6.2
z_{str}	depth of structural element below surface above it	m	Clause 6.10.2
α	hopper half angle	degrees	Clauses 6.2.3.3, 6.2.3.6, 6.3.5, 6.6.2
β	circumferential coordinate	degrees	Clauses 6.4.1, 6.5.2.2
β_e	circumferential range of pressure reduction	degrees	Clause 6.5.2.3
β_1	circumferential angular coordinate with origin in the direction of the earthquake	degrees	Clause 7.4.3.2
γ	unit weight of the bulk solid	kN/m ³	Clauses 3.2, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.3.1, 6.2.3.3, 6.2.3.6, 6.3.4, 6.3.5, 6.4.1, 6.4.2, 6.6.1, 6.6.2, 6.8.3, 6.10.2, 7.4.3.2, 7.4.3.3, 7.5, Table 3.1

(continued)

TABLE 1.1 (continued)

Quantity symbol	Term	Unit symbol	Text reference
δ	coefficient of variation	—	Clause B2
ϵ_C	coefficient of thermal expansion of column	—	Clause 7.3.3
ϵ_w	coefficient of thermal expansion of the wall	—	Clause 7.3.2
η	angle variable	degrees	Clause 6.3.5
θ	temperature rise	°C	Clause 7.3.2
$\Delta\theta_i$	temperature differential between the subject column and the reference value	°C	Clause 7.3.3
κ	modulus contiguity coefficient	—	Clause 3.4.6
μ	coefficient of wall friction	—	Clauses 6.2.1.1, 6.2.1.2, 6.2.1.9, 6.2.2.1, 6.2.3.1, 6.2.3.6, 6.3.2.3, 6.4.1, 7.5
μ_{eff}	effective wall friction coefficient	—	Clause B3
μ_h	hopper wall friction coefficient	—	Clauses 6.2.3.3, 6.2.3.4, 6.3.5, 6.3.6, 6.6.2
μ_i	internal friction coefficient	—	Clause B3
μ_w	wall friction coefficient (flat wall surface)	—	Clause B3
ν	Poisson ratio for the solid	—	Clause 7.3.2
ϕ_i	effective angle of internal friction	degrees	Clauses 3.2, 6.1.4, 6.1.5, 6.2.1.1, 6.2.2.1, 6.2.3.1, 6.3.2.2, 6.3.4, 6.3.5, 6.5.2.2, 6.6.3, B3, C1
ϕ_r	angle of repose of poured bulk solid	degrees	Clauses 2.2.2, 3.2, 6.4.1, Table 3.1
ϕ_{st}	static angle of internal friction	degrees	Clause C1
ϕ_w	angle of wall friction	degrees	Clauses 3.2, 6.1.3, 6.1.5, 6.2.1.1, 6.2.2.1, 6.2.3.1, 6.2.3.3, 6.2.3.4, 6.3.5, B3, Tables 3.1, 6.1, 6.3
ψ	wall flexibility factor	—	Clause 6.2.1.8

SECTION 2 CLASSIFICATION AND GEOMETRIC PARAMETERS OF BULK STORAGE CONTAINERS

2.1 CLASSIFICATION OF CONTAINERS

2.1.1 Bases of classification system Containers shall be classified according to the following characteristics:

- (a) Container geometry (see Clause 2.1.2).
- (b) Flow mode during discharge (see Clause 2.1.3).
- (c) Flow geometry (see Clause 2.1.4).
- (d) Roughness of internal wall surfaces (see Clause 2.1.5).
- (e) Flexibility of walls in the hoop direction (see Clause 2.1.6).
- (f) Continuity of walls in the vertical direction (see Clause 2.1.7).
- (g) Cross-sectional shape (see Clause 2.1.8).
- (h) Configuration of discharge outlets (see Clause 2.1.9).
- (i) Means of flow promotion (see Clause 2.1.10).

2.1.2 Container geometry The ratio of the overall effective height of stored bulk solid (h_b) to the largest inscribed diameter (d_c) shall be designated as follows:

- (a) Type A1: Squat with $h_b/d_c < 1.0$.
- (b) Type A2: Medium tall with $1.0 \leq h_b/d_c \leq 3.0$.
- (c) Type A3: Tall with $h_b/d_c > 3.0$.

Figure 2.1 illustrates the container geometries for containers of different h_b/d_c ratios and shall apply to containers of all shapes of plan cross-section. See Figure 2.6 for definition of h_b and Table 2.2 for definition of d_c .

2.1.3 Flow mode The flow mode depends on the hopper half-angle, wall roughness, properties of the stored material, and other factors, and shall be designated as follows:

- (a) Type B1: Mass flow.
- (b) Type B2: Funnel flow.
- (c) Type B3: Pipe flow.
- (d) Type B4: Expanded flow.
- (e) Type B5: Eccentric flow.

Figures 2.2 and 2.3 illustrate the flow modes, trajectories, and flow zones.

NOTE: The description of the flow modes is to be regarded as approximations of the flow of bulk solids in actual containers.

To aid in the preliminary design of the hopper geometry, Figure 2.4 indicates the boundaries between mass flow and funnel flow modes. Due to considerable uncertainties in the material properties and the roughness of the walls, the graphs indicate approximate upper and lower bounds. For reliable mass flow, the hopper half-angle shall be chosen using the lower bound curve.

The possibility of changes to the flow mode due to changes in wall roughness, material properties, and other factors shall be considered.

2.1.4 Flow geometry The flow geometry shall be designated as follows:

- (a) Type C1: Axisymmetric path where the centre of gravity of the flowing material roughly coincides with the vertical container axis, e.g. circular container with concentric discharge opening.
- (b) Type C2: Planar path where the flow channel is symmetrical about the plane through the longitudinal axis of the rectangular hopper, e.g. slot bunker.
- (c) Type C3: Eccentric path where the flow is unsymmetrical about the vertical axis of the container, or about the vertical plane through the longitudinal axis of the container.
- (d) Type C4: Eccentric free surface configuration arising from filling or discharge in squat containers (see Figure 2.5).

2.1.5 Roughness of wall surfaces The surface roughness is quantified as the mean centre-line roughness of the wall surfaces, and shall be designated as given in Table 2.1.

TABLE 2.1
DESIGNATION OF SURFACE ROUGHNESS

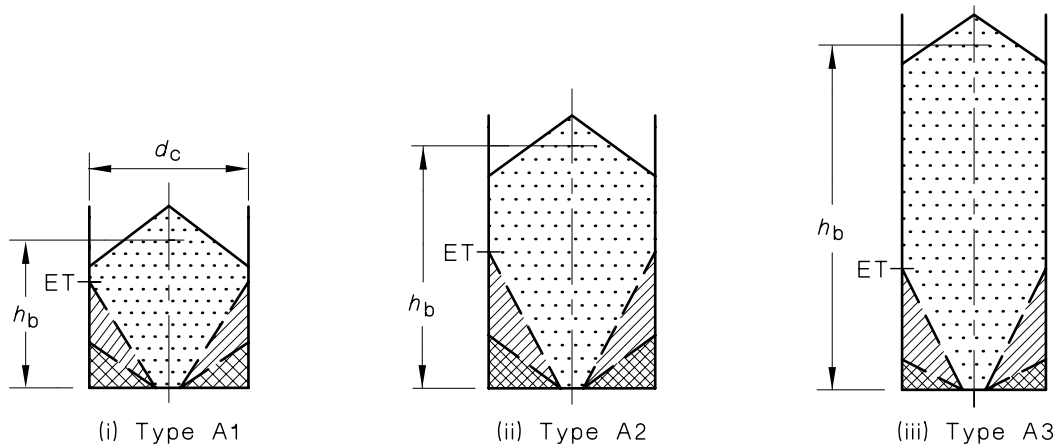
Type	Description of surface	Mean centreline roughness, μm	Typical materials
D1	Polished	0.01 to 1	Polished stainless steel, extruded high density polyvinyl ethylene, galvanized carbon steel, aluminium
D2	Smooth	1 to 10	Pickled stainless steel, cast high-density polyvinyl ethylene, painted carbon steel, carbon steel with light surface rust, smooth ceramic tiles, steel-finished concrete, profiled sheeting with vertical ribs—mobile bulk solid
D3	Rough	10 to 1000	Off-form concrete, pitted carbon steel, coarse ceramic tiles, profiled sheeting with vertical ribs—immobile bulk solid
D4	Corrugated	>1000	Profiled sheeting with horizontal ribs

The influence of discontinuities such as protrusions due to butt welds and lap joints in the wall plates shall also be considered.

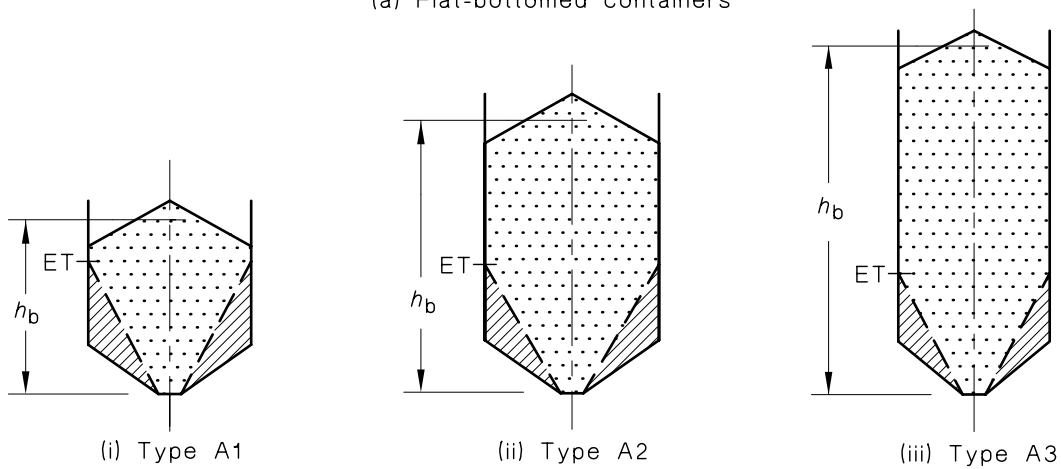
The wall roughness may not necessarily remain constant with time and shall be considered as a variable. The design shall assume the widest range of possible roughness expected.

Due to corrosion and hence rapid deterioration of carbon steel surfaces in the presence of moisture, these surfaces can exhibit wall friction ranging from Type D1 to Type D3.

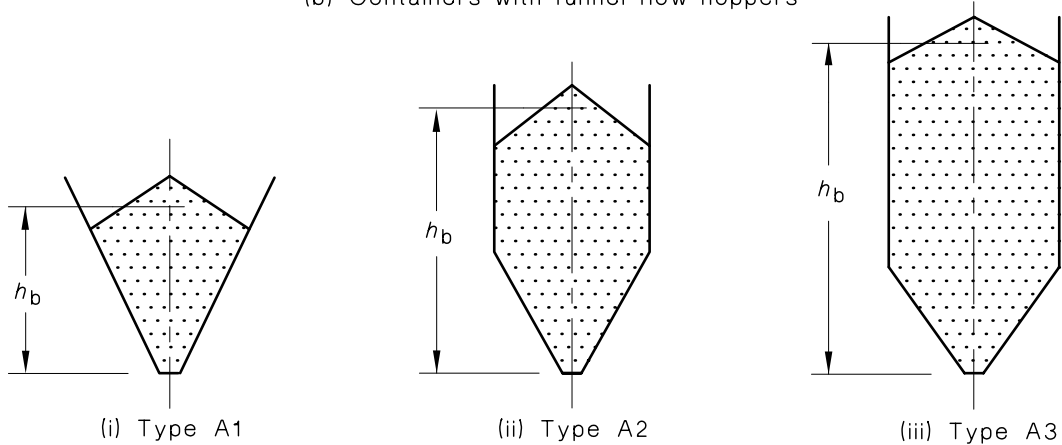
The roughness categories given in Table 2.1 may vary with time. Wall surfaces in Type D1 may deteriorate to Type D3. However, wall surfaces of Type D3 cannot deteriorate to Type D4. Similarly polishing of wall surfaces can occur, and a change in Type from Type D2 to Type D1 or from Type D3 to Type D2 may occur. However, polishing of wall surfaces in Type D4 need not be considered.



(a) Flat-bottomed containers



(b) Containers with funnel flow hoppers



(c) Containers with mass flow hoppers

LEGEND:

ET = effective transition (location is variable)

Primary flow zone
 Secondary flow zone
 Dead zone

FIGURE 2.1 CONTAINER GEOMETRIES

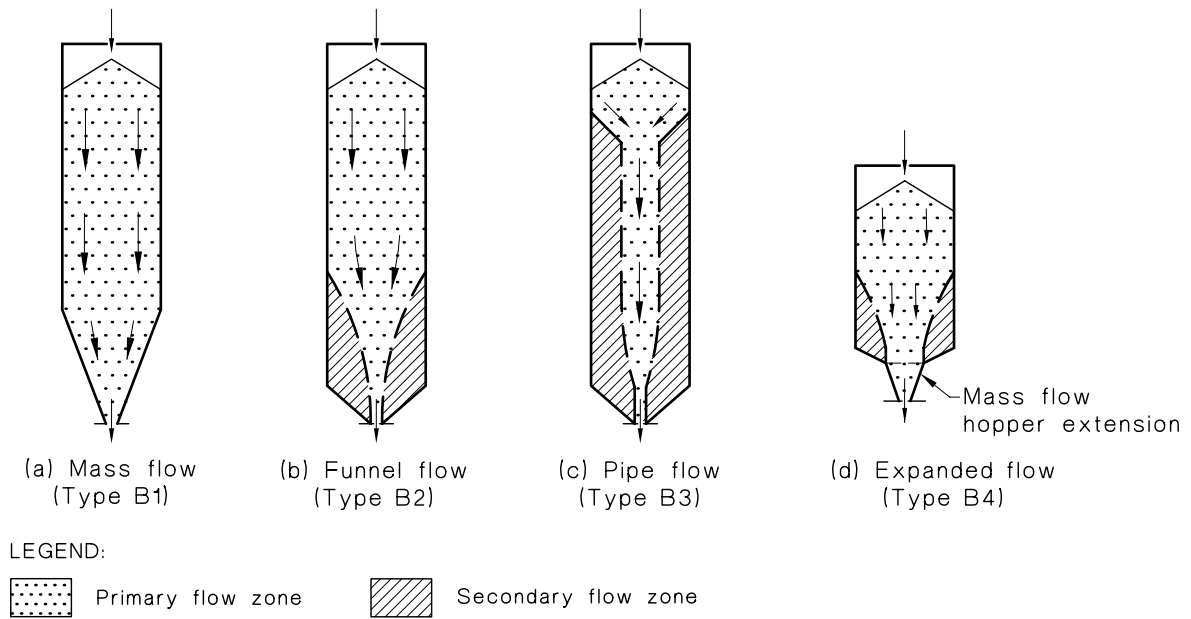


FIGURE 2.2 SYMMETRICAL FLOW MODES

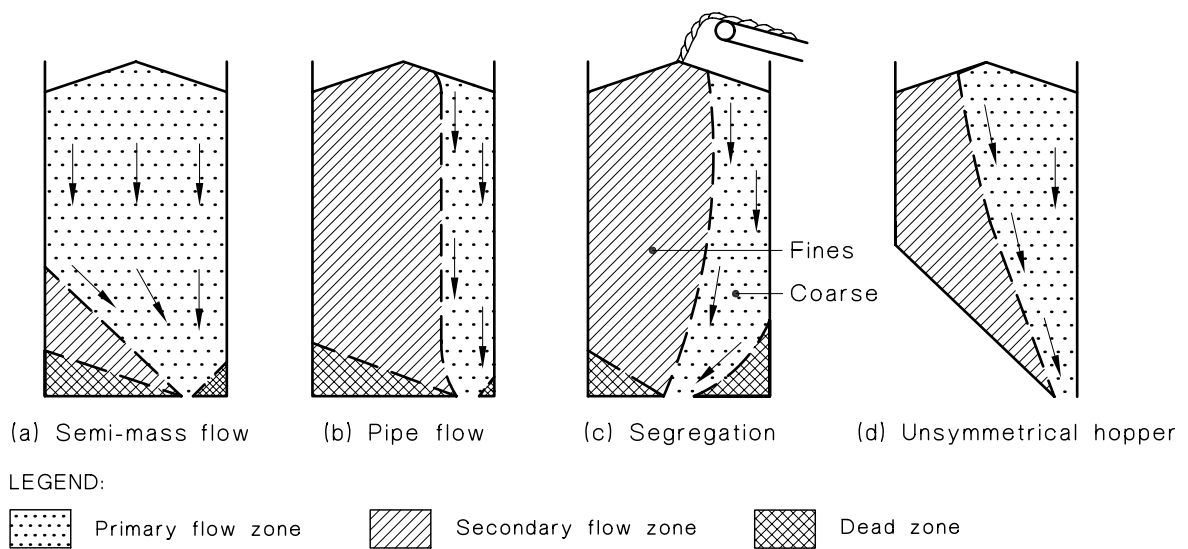


FIGURE 2.3 ECCENTRIC FLOW CHANNEL CONFIGURATIONS (TYPE B5)

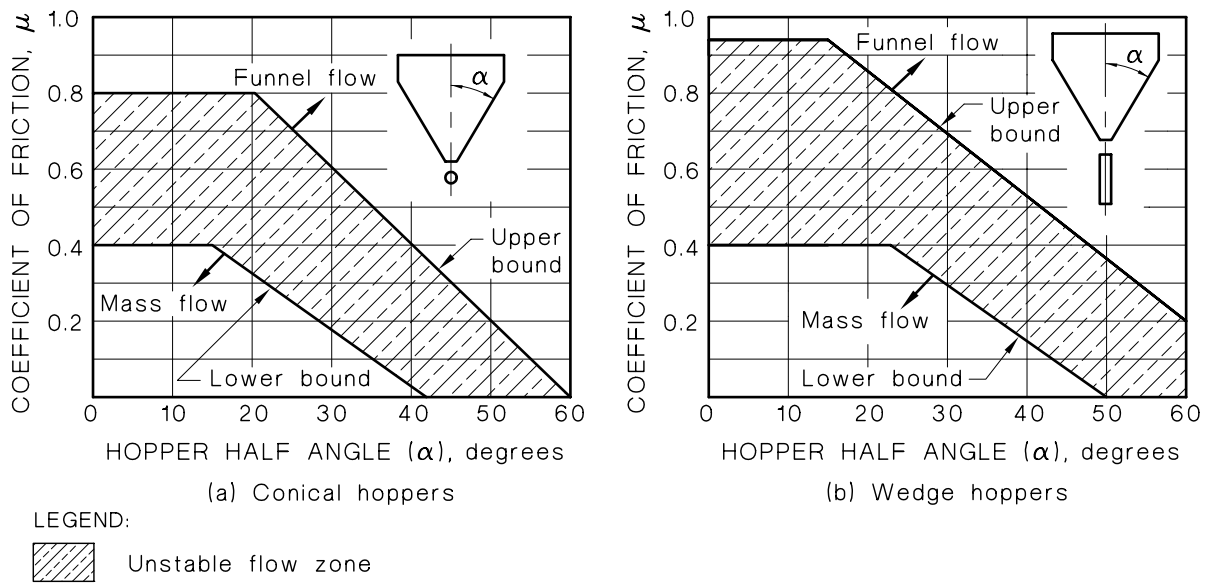


FIGURE 2.4 THE BOUNDARIES BETWEEN MASS FLOW AND FUNNEL FLOW

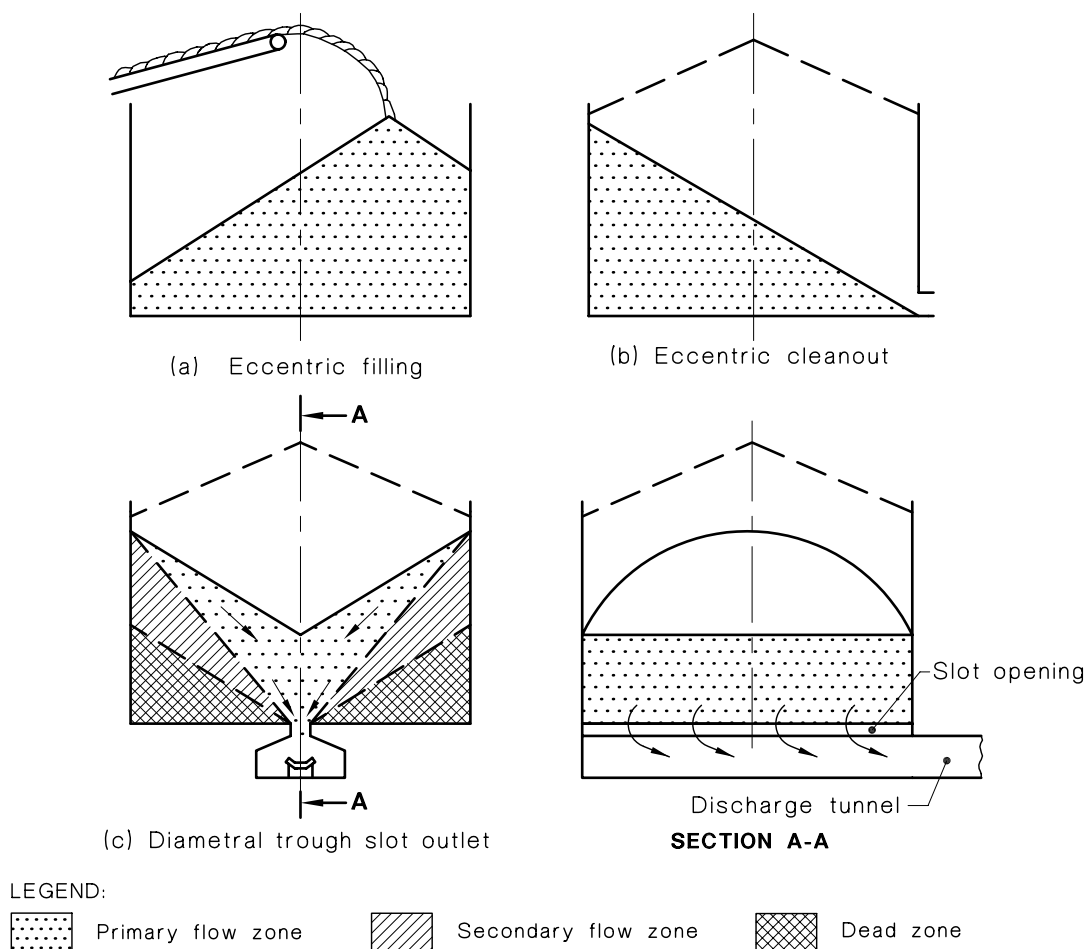


FIGURE 2.5 UNSYMMETRICAL CONDITIONS IN SQUAT CONTAINERS

2.1.6 Flexibility of walls in the hoop direction The flexibility of the walls in the hoop direction shall be designated as follows:

- (a) Type E1: Rigid, having an inscribed diameter (d_c) to wall thickness (t) ratio less than 100.
- (b) Type E2: Semirigid, having an inscribed diameter (d_c) to wall thickness (t) ratio between 100 and 500.
- (c) Type E3: Flexible, circular containers wall diameter (d_c) to wall thickness (t) ratio greater than 500, or metal square or rectangular containers.

2.1.7 Continuity of walls in the vertical direction The continuity of the walls in the vertical direction shall be designated as follows:

- (a) Type F1: Two-way continuous walls, e.g. fully welded steel containers and reinforced or prestressed concrete containers with a minimum of 0.35% vertical reinforcement.
- (b) Type F2: Discontinuous walls, e.g. segmental containers in reinforced concrete and corrugated metal containers with horizontal corrugations.

2.1.8 Cross-sectional shapes Cross-sectional shapes shall be designated as given in Table 2.2.

2.1.9 Configuration of discharge outlets The configuration of discharge outlets shall be designated as follows:

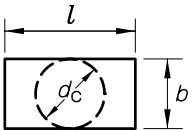
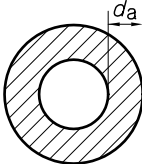
- (a) Type H1: Centrally located circular or square discharge outlet, and designed for uniform flow across the entire outlet area.
- (b) Type H2: Slot type discharge opening located on the centre-line of the container and designed for uniform flow along its length.
- (c) Type H3: Eccentrically placed circular or square discharge opening, or a series of such openings around circumference.
- (d) Type H4: Discharge opening situated in the wall of the container.

Configuration of Type H3 and H4 lead to eccentric flow and non-uniform loads on the container.

2.1.10 Means of flow promotion The means of flow promotion shall be designated as follows:

- (a) Type J1: Gravity alone.
- (b) Type J2: Mechanical vibrators.
- (c) Type J3: Induction of air over the whole or part of the surface of the container closure.
- (d) Type J4: Impulsive devices, e.g. air cannons/blasters, blasting, mechanical shocks.
- (e) Type J5: Combined flow promotion.

TABLE 2.2
DESIGNATION OF CROSS-SECTIONAL SHAPES

Type	Cross-section	Characteristic dimension (r_c)	Diagram
G1	Circular	$0.25d_c$	
G2	Square	$0.25d_c$	
G3	Rectangular For calculations referred to the short side (b) For $l/b = 1.0$ For $l/b = 1.5$ For $l/b = 2.0$ For $l/b = 4.0$ For $l/b = 5.0$ For calculations referred to the long side (l) For $l/b = 1.5$ For $l/b = 2.0$ For $l/b = 4.0$ For $l/b = 5.0$	$0.25d_c$ $0.27d_c$ $0.30d_c$ $0.33d_c$ $0.35d_c$ $0.30d_c$ $0.33d_c$ $0.40d_c$ $0.50d_c$	
G4	Star-shaped	$0.30d_c$	
G5	Polygonal	$0.27d_c$	
G6	Annular	$0.35d_a$	
G7	Irregular	$0.30d_c$	

2.2 GEOMETRIC PARAMETERS OF CONTAINERS

2.2.1 Basic parameters Figure 2.6 shows the basic geometric parameters of containers, unless the roof is flatter than the angle of repose. These parameters apply to containers of all shapes of plan cross-section. The toe of the filling surface shall be at the top of the vertical section of the container.

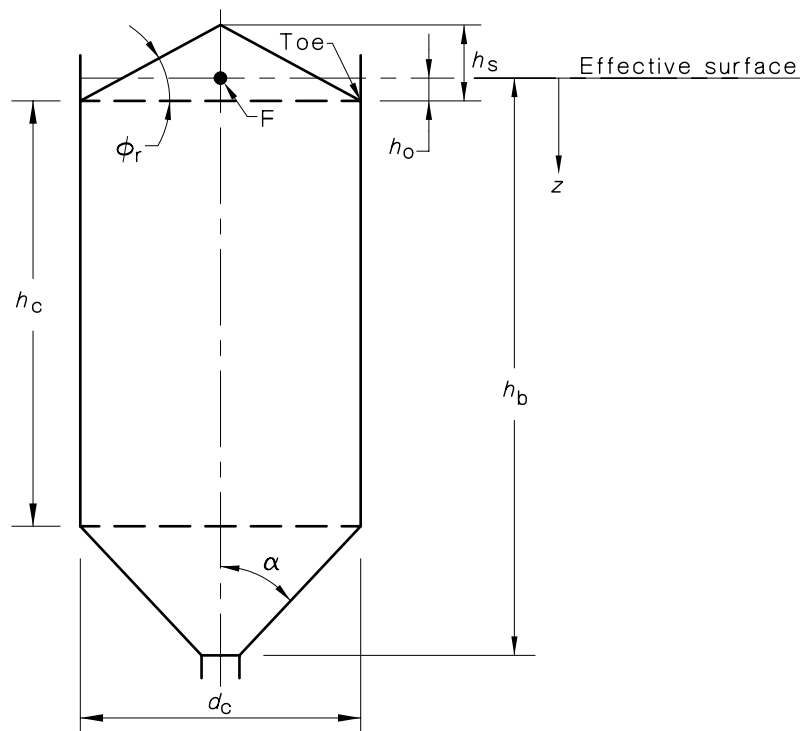


FIGURE 2.6 CHARACTERISTIC GEOMETRIC PARAMETERS

2.2.2 Origin of vertical coordinate The origin of the vertical coordinate (z) used in the load calculation shall be at point F as shown in Figure 2.6, and shall be found at a height h_o vertically above the highest bulk solid/wall contact. The value of h_o shall be as follows:

- (a) For level surface $h_o = 0$.
- (b) For conical surface $h_o = h_s/3$.
- (c) For long prismatic pile $h_o = h_s/2$.

In the determination of the storage shape, account shall be taken of—

- (i) dimension h_s , where $h_s = (d_c/2) \tan \phi_r$; and
- (ii) eccentricity of filling due to conveyor trajectory or chute inclination at angle (see Figure 2.5, Clause 6.4, and Equation 6.4.1(4)).

2.3 CONTAINER CAPACITY The storage capacity of a container shall be described by its volumetric capacity. The volumetric capacity shall be expressed in terms of either 'level full' or 'peaked storage capacity'. These capacities vary depending on whether the container is open-eave or tight-eave.

The nominal mass capacity of the container shall be calculated from its volumetric capacity and the average bulk density given in Table 3.1.

SECTION 3 PROPERTIES OF BULK SOLIDS

3.1 CLASSIFICATION Bulk solids shall be classified according to their particle size as follows:

- (a) Powder less than 0.15 mm.
- (b) Fine grain less than 3 mm.
- (c) Coarse grain less than 12 mm.
- (d) Lumpy more than 12 mm.
- (e) Irregular fibrous, stringy, and the like.

3.2 PROPERTIES FOR LOADING CALCULATION The following properties shall be used to determine the loads due to stored bulk solids:

- (a) Unit weight of bulk solid (γ).
- (b) Effective angle of internal friction (ϕ_i).
- (c) Angle of wall friction (ϕ_w).
- (d) Angle of repose (ϕ_r).

Representative values of bulk solids properties are given in Clause 3.4.

3.3 OTHER PROPERTIES Other bulk solid properties that need to be considered in the design of the container are as follows:

- (a) Flowability.
- (b) Abrasiveness.
- (c) Corrosiveness.
- (d) Susceptibility to dust explosion or gas explosion.
- (e) Volumetric stability.
- (f) Tendency to degrade or weather.

Appendix B gives further information on these properties for a limited range of bulk solids.

3.4 REPRESENTATIVE VALUES

3.4.1 General Two representative values for each property shall be used to determine the loads due to stored bulk solid, viz. an upper characteristic value and a lower characteristic value. These two values represent the range of values that a property may exhibit.

Characteristic values to be used in loading calculations shall be—

- (a) values agreed between the parties concerned;
- (b) values given in Table 3.1; or
- (c) values derived from appropriate test data (see Appendix C) with the upper and lower characteristic values determined using the method described in Paragraph C2, Appendix C.

For materials not listed in Table 3.1, the values of properties shall be estimated from available data consistent with the definitions of representative values given in Clauses 1.3.4 and 1.3.5.

3.4.2 Unit weight For loading calculations, the unit weight shall be the upper characteristic value of bulk weight. For volume estimates, the unit weight shall be the average bulk weight.

NOTE: Based on experience or measurement, unit weight values lower than the average may be used.

3.4.3 Effective angle of internal friction The angle of internal friction shall be the upper characteristic value or the lower characteristic value according to the application.

3.4.4 Angle of wall friction The angles of wall friction of the stored bulk solid sliding on the internal surface of the container shall be the upper characteristic value or the lower characteristic value according to the application.

For roughness of Type D4, the angle of wall friction shall be computed from an appropriate linear combination of the angle of internal friction and the angle of wall friction for roughness of Type D1 according to the type of profiled sheeting using the method described in Paragraph B3, Appendix B.

For the design of containers comprising profiled sheeting with the corrugations parallel to the flow direction, the upper characteristic wall friction coefficient shall be taken as the maximum of—

$c_p \times$ measured flat sheet wall friction coefficient adjusted for the presence of fasteners and joints;

and

the upper characteristic value given in Table 3.1

where

c_p = the ratio of the profiled contact circumference per pitch to the nominal profile pitch (see Figure B1).

In such containers, caution shall also be exercised where the bulk solid in the corrugations may become immobile. For such wall contact, the upper characteristic wall friction coefficient shall be evaluated using Equation B3.

3.4.5 Angle of repose The angle of repose shall be the mean value.

3.4.6 Effective elastic modulus The upper bound elastic modulus of the solid depends on the vertical stress in it. At a given height (z) in the container, the elastic modulus shall be given by the following equation:

$$E_s = \chi p_{vi} \quad \dots 3.4.6(1)$$

where

E_s = upper bound elastic modulus of bulk solid, in kilopascals

χ = modulus contiguity coefficient

p_{vi} = initial vertical pressure on a horizontal plane, determined from Equation 6.2.3.1(1), in kilopascals.

In the absence of experimental data from confined tests on the solid, the value of χ shall be determined from the following equation:

$$\chi = 3\gamma^{3/2} \quad \dots 3.4.6(2)$$

where

χ = modulus contiguity coefficient

γ = unit weight of bulk solid, in kilonewtons per cubic metre.

Alternatively, the value of χ may be taken as 70 for dry agricultural grains, 100 for small mineral particles, and 150 for very large hard mineral particles.

3.5 COMBINATION OF CHARACTERISTIC VALUES Appropriate characteristic values of properties shall be used to produce maximum calculated load effects on the container.

TABLE 3.1
CHARACTERISTIC VALUES OF PHYSICAL PROPERTIES OF BULK SOLIDS

Type of bulk solid	Unit weight (γ) kN/m ³		Mean angle of repose (ϕ_r) degrees	Effective angle of internal friction (ϕ_i) degrees		Angle of wall friction (ϕ_w), degrees						Vertical pressure multiplier (C_{vf})
						Roughness*						
	Type D1			Type D2		Type D3						
								Lower	Upper	Lower	Upper	
Alumina	10.0	12.0	27	25	40	20	25	25	30	30	35	1.2
Barley	7.0	8.5	20	26	33	15	24	18	27	25	32	1.4
Cement	13.0	16.0	28	40	50	20	25	23	28	28	33	1.2
Cement clinker	15.0	18.0	33	42	52	20	25	25	30	30	35	1.2
Coal—												
Black	8.5	11.0	35	40	60	15	25	25	35	25	40	1.4
Brown	7.0	9.0	33	45	65	18†	25†	25	35	35	45	1.4
Powdered	6.0	9.0	38	40	50	20	24	24	28	27	32	1.2
Coke—												
Breeze	7.0	8.0	40	35	45	22	27	26	33	28	35	1.3
Petroleum	6.5	7.5	38	37	47	24	29	28	35	30	37	1.3
Concrete aggregate, 0 to 28 mm, moist	17.0	19.0	34	30	40	15	25	18	30	25	35	1.3
Flour (wheat)	6.5	7.5	40	23	30	15	23	25	28	25	35	1.4
Fly ash	8.0	11.5	22	30	35	18	25	25	35	30	40	1.2
Iron ore, pellets	19.0	22.0	35	35	45	20	25	26	33	28	35	1.3
Lime, hydrated	6.0	8.0	40	35	45	18	25	25	33	30	40	1.2
Limestone powder	11.0	13.0	30	40	60	15	25	23	30	28	40	1.3
Maize	7.0	8.5	30	28	33	15	25	20	30	25	32	1.6
Phosphate rock	16.0	19.0	27	35	55	19	25	22	30	25	32	1.3
Sand—												
Coarse, dry	14.0	17.0	30	30	40	15	25	22	28	25	35	1.3
Quartz	15.0	17.0	30	35	40	15	22	15	22	20	26	1.4
Slag, furnace, granular, dry	10.5	12.0	40	35	38	16	22	20	25	24	28	1.4
Soya beans	7.0	8.0	23	25	32	10	15	12	18	14	20	1.4
Sugar	8.0	10.0	29	33	38	15	25	20	35	25	40	1.2
Wheat	7.5	9.0	23	26	32	15	25	18	30	25	32	1.4

*For roughness Type D4, see Appendix B.

†Values tabulated are for a polyethylene wall liner.