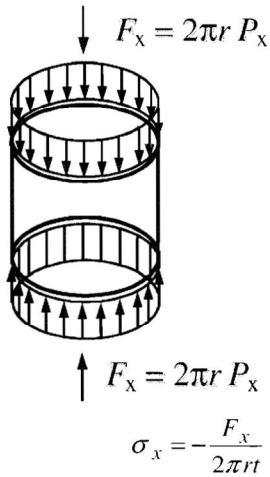
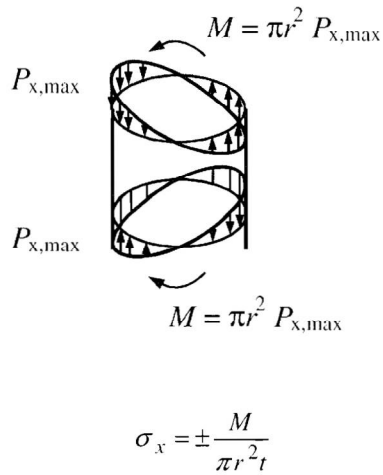


A.2 Unstiffened cylindrical shells

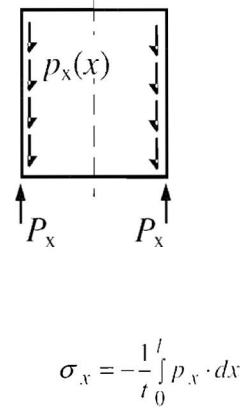
A.2.1 Uniform axial load



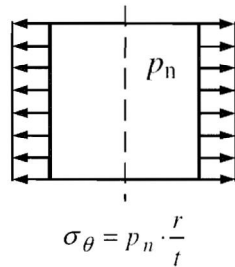
A.2.2 Axial load from global bending



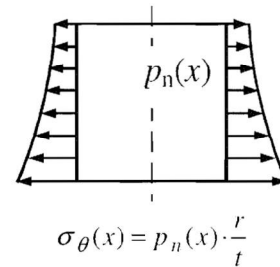
A.2.3 Friction load



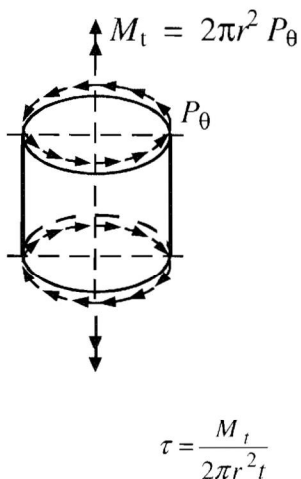
A.2.4 Uniform internal pressure



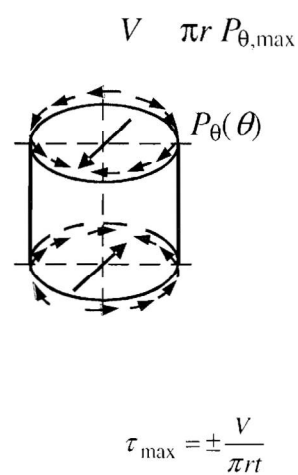
A.2.5 Variable internal pressure



A.2.6 Uniform shear from torsion

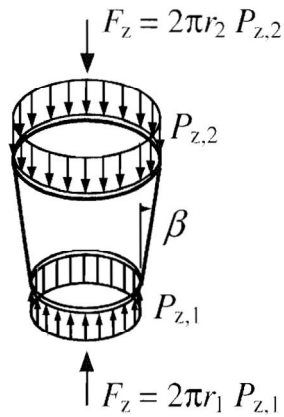


A.2.7 Sinusoidal shear from transverse force



A.3 Unstiffened conical shells

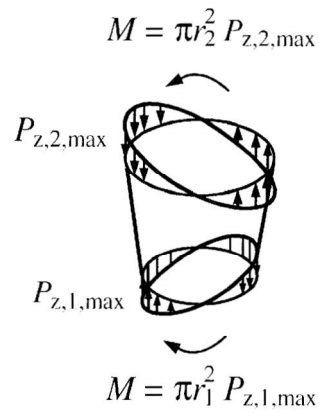
A.3.1 Uniform axial load



$$\sigma_x = -\frac{F_z}{2\pi r t \cdot \cos \beta}$$

$$\sigma_\theta = 0$$

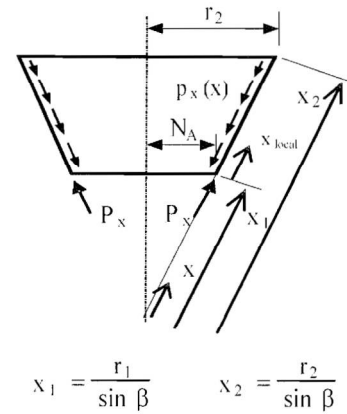
A.3.2 Axial load from global bending



$$\sigma_{x,max} = \pm \frac{M}{\pi r^2 t \cdot \cos \beta}$$

$$\sigma_\theta = 0$$

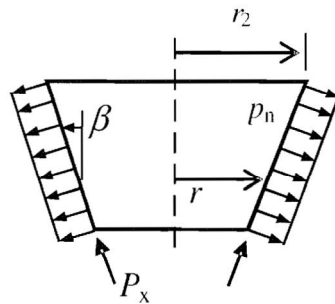
A.3.3 Friction load



$$\sigma_{x1} = -\frac{1}{x_1 t} \int_{x_1}^{x_2} p_x x \cdot dx$$

$$\sigma_\theta = 0$$

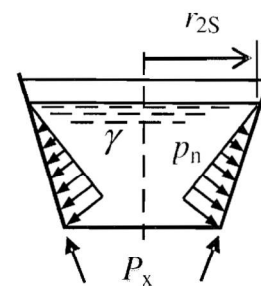
A.3.4 Uniform internal Pressure



$$\sigma_x = -p_n \frac{r}{2t \cdot \cos \beta} \left[\left(\frac{r_2}{r} \right)^2 \right]$$

$$\sigma_\theta = p_n \frac{r}{t \cdot \cos \beta}$$

A.3.5 Linearly varying internal pressure

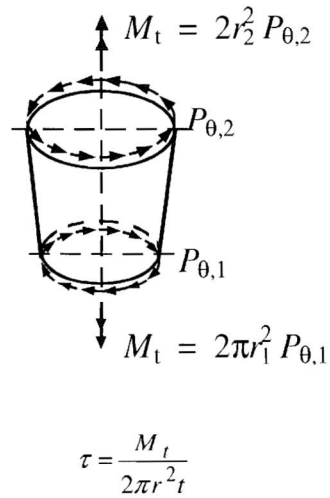


r_{2s} is the radius at the fluid surface

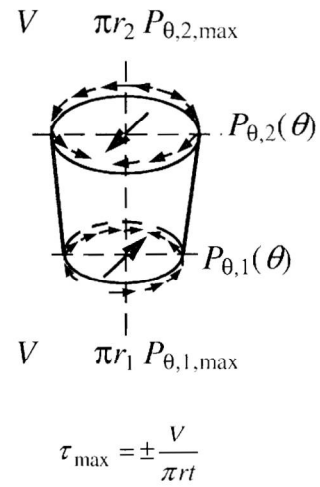
$$\sigma_x = -\frac{\gamma r}{t \cdot \sin \beta} \left\{ \frac{r_{2s}}{6} \left[\left(\frac{r_{2s}}{r} \right)^2 - 3 \right] + \frac{r}{3} \right\}$$

$$\sigma_\theta = +\frac{\gamma r}{t \cdot \sin \beta} (r_{2s} - r)$$

A.3.6 Uniform shear from torsion

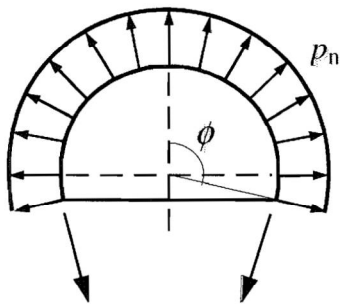


A.3.7 Sinusoidal shear from transverse force

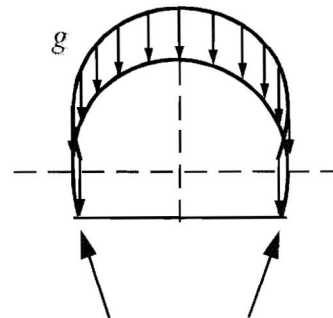


A.4 Unstiffened spherical shells

A.4.1 Uniform internal pressure



A.4.2 Uniform self-weight load



or a vertical stiffener on a box. It is used to distribute transverse loads on the structure by bending action.

1.5.17 ring stiffener: A ring stiffener is a local stiffening member that passes around the circumference of the structure at a given point on the meridian. It is assumed to have no stiffness in the meridional plane of the structure. It is provided to increase the stability or to introduce local loads, not as a primary load-carrying element. In a shell of revolution it is circular, but in rectangular structures it takes the rectangular form of the plan section.

1.5.18 smeared stiffeners: Stiffeners are said to be smeared when the properties of the shell wall and the individual stiffeners are treated as a composite section using a width equal to an integer multiple of the separation of the stiffeners. The stiffness properties of a shell wall with smeared stiffeners are orthotropic with eccentric terms leading to coupling between bending and stretching behaviour.

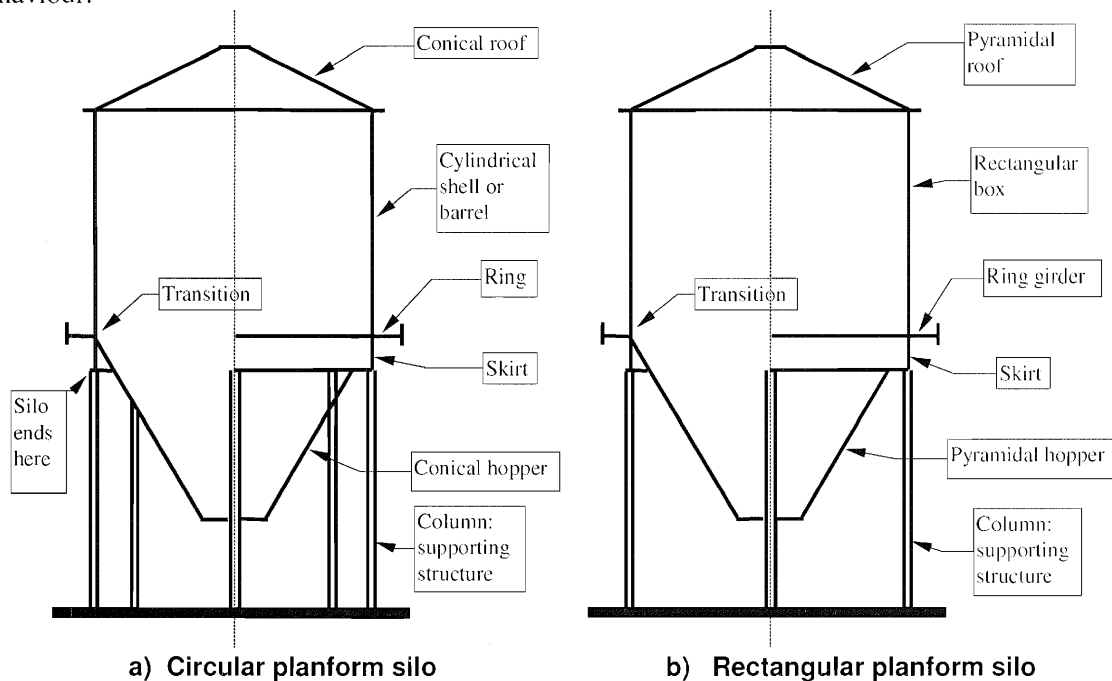


Figure 1.1: Terminology used in silo structures

1.5.19 base ring: A base ring is a structural member that passes around the circumference of the structure at the base and provides means of attachment of the structure to a foundation or other element. It is required to ensure that the assumed boundary conditions are achieved in practice.

1.5.20 ring girder or ring beam: A ring girder or ring beam is a circumferential stiffener which has bending stiffness and strength both in the plane of the circular section of a shell or the plan section of a rectangular structure and also normal to that plane. It is a primary load-carrying element, used to distribute local loads into the shell or box structure.

1.5.21 continuous support: A continuously supported silo is one in which all positions around the circumference are supported in an identical manner. Minor departures from this condition (e.g. a small opening) need not affect the applicability of the definition.

1.5.22 discrete support: A discrete support is a position in which a silo is supported using a local bracket or column, giving a limited number of narrow supports around the silo circumference. Four or six discrete supports are commonly used, but three or more than six are also found.

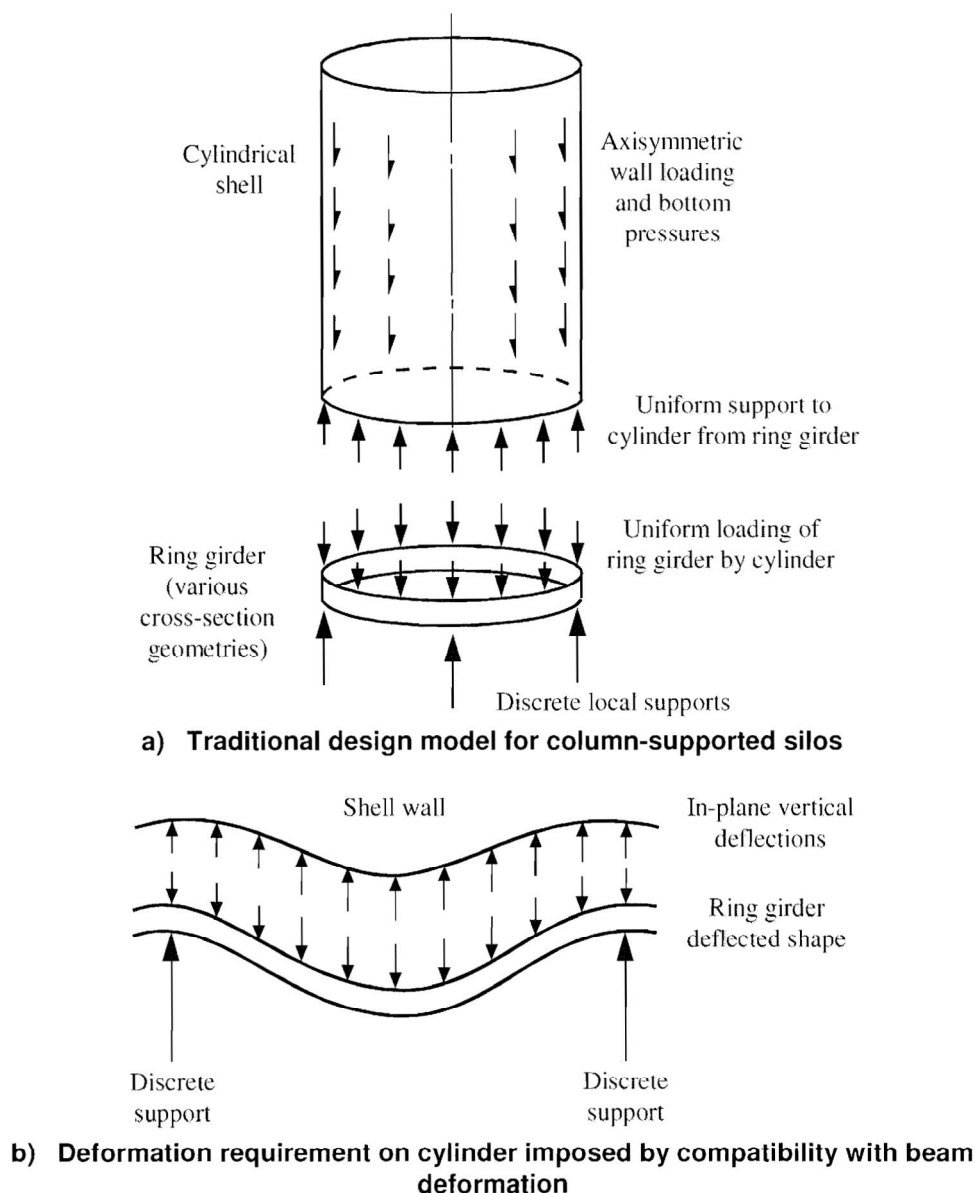


Figure 4.1: Axial deformation compatibility between ring girder and shell

(10) Where the silo is subject to any form of unsymmetrical bulk solids loading (patch loads, eccentric discharge, unsymmetrical filling etc.), the structural model should be designed to capture the membrane shear transmission within the silo wall and between the wall and rings.

NOTE: The shear transmission between parts of the wall and rings has special importance in construction using bolts or other discrete connectors (e.g. between the wall and hopper, between different strakes of the barrel).

(11) Where a ring girder is used to redistribute silo wall forces into discrete supports, and where bolts or discrete connectors are used to join the structural elements, the shear transmission between the parts of the ring due to shell bending and ring girder bending phenomena should be determined.

(12) Except where a rational analysis is used and there is clear evidence that the solid against the wall is not in motion during discharge, the stiffness of the bulk solid in resisting wall deformations or in increasing the buckling resistance of the structure should not be considered.

5 Design of cylindrical walls

5.1 Basis

5.1.1 General

- (1) Cylindrical steel silo walls should be so proportioned that the basic design requirements for the ultimate limit states given in section 2 are satisfied.
- (2) The safety assessment of the cylindrical shell should be conducted using the provisions of EN 1993-1-6.

5.1.2 Silo wall design

- (1) The cylindrical wall of the silo should be checked for the following phenomena under the limit states defined in EN 1993-1-6:
 - global stability and static equilibrium.

LS1: plastic limit state

- resistance to bursting or rupture or plastic mechanism collapse (excessive yielding) under internal pressures or other actions;
- resistance of joints (connections).

LS2: cyclic plastification

- resistance to local yielding in bending;
- local effects.

LS3: buckling

- resistance to buckling under axial compression;
- resistance to buckling under external pressure (wind or vacuum);
- resistance to buckling under shear from unsymmetrical actions;
- resistance to buckling under shear near engaged columns;
- resistance to local failure above supports;
- resistance to local crippling near openings;
- resistance to local buckling under unsymmetrical actions;

LS4: fatigue

- resistance to fatigue failure.

- (2) The shell wall should satisfy the provisions of EN 1993-1-6, except where 5.3 to 5.6 provide conditions that are deemed to satisfy the provisions of that standard.

- (3) For silos in Consequence Class 1, the cyclic plasticity and fatigue limit states may be ignored.

5.2 Distinctions between cylindrical shell forms

- (1) For a shell wall constructed from flat rolled steel sheet, termed 'isotropic' (see figure 5.1), the resistances should be determined as defined in 5.3.2.

- (2) For a shell wall constructed from corrugated steel sheets where the troughs run around the silo circumference, termed 'horizontally corrugated' (see figure 5.1), the resistances should be determined as defined in 5.3.4. For a shell wall with the troughs running up the meridian, termed 'vertically corrugated', the resistances should be determined as defined in 5.3.5.

(3) For a shell wall with stiffeners attached to the outside, termed 'externally stiffened' irrespective of the spacing of the stiffeners, the resistances should be determined as defined in 5.3.3.

(4) For a shell wall with lap joints formed by connecting adjacent plates with overlapping sections, termed 'lap-jointed' (see figure 5.1), the resistances should be determined as defined in 5.3.2.

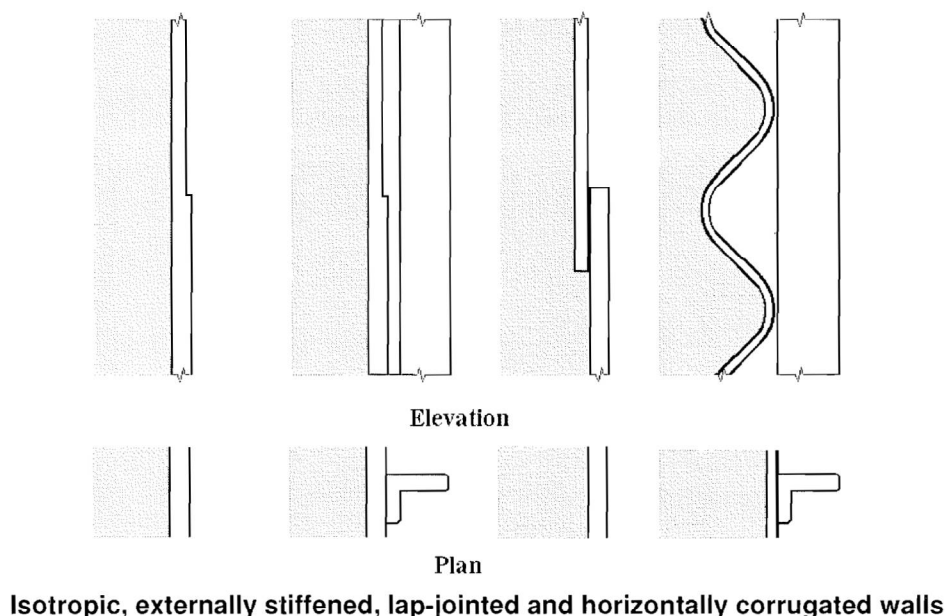


Figure 5.1: Illustrations of cylindrical shell forms

5.3 Resistance of silo cylindrical walls

5.3.1 General

(1) The cylindrical shell should satisfy the provisions of EN 1993-1-6. These may be met using the following assessments of the design resistance.

5.3.2 Isotropic welded or bolted walls

5.3.2.1 General

(1) The shell wall cross-section should be proportioned to resist failure by rupture or plastic collapse.

(2) The joints should be proportioned to resist rupture on the net section using the ultimate tensile strength.

(3) The eccentricity of lap joints should be included in the strength assessment for rupture, when relevant.

(4) The shell wall should be proportioned to resist stability failure.

5.3.2.2 Evaluation of design stress resultants

(1) Under internal pressure, frictional traction and all relevant design loads, the design stress resultants should be determined at every point in the shell using the variation in internal pressure and wall frictional traction, as appropriate.