BUNKERS AND SILOS

INTRODUCTION

Bunkers and silos are structures meant for storing materials like cement, coal, wheat, broken stone, clinker etc. Bins are used by a wide range of industries to store bulk solids in quantities ranging from a few tonnes to over one hundred thousand tones. A bin is an upright container for the storage of bulk granular materials. Shallow bins are usually called as bunkers and deep bins are usually called as silos

- A bunker is a shallow structure in which the plane of rupture of the material stored meets the surface of the stored material before meeting the opposite side of structure.
- A silo is a tall structure in which the plane of rupture of the material stored meets the opposite face of the structure before meeting the surface of the stored material.

Applications

A bunker is a defensive military fortification designed to protect people or valued materials from falling bombs or other attacks. Bunkers are mostly underground, compared to blockhouses which are mostly above ground. They were used extensively in World War I, World War II, and the Cold War for weapons facilities, command and control centers, and storage facilities (for example, in the event of nuclear war). Bunkers can also be used as protection from tornadoes.

Trench bunkers are small concrete structures, partly dug into the ground. Many artillery installations, especially for coastal artillery, have historically been protected by extensive bunker systems. Typical industrial bunkers include mining sites, food storage areas, dumps for materials, data storage, and sometimes living quarters. When a house is purpose-built with a bunker, the normal location is a reinforced below-ground bathroom with fiber-reinforced plastic shells. Bunkers deflect the blast wave from nearby explosions to prevent ear and internal injuries to people sheltering in the bunker. Nuclear bunkers must also cope with the under pressure that lasts for several seconds after the shock wave passes, and block radiation.

A bunker's door must be at least as strong as the walls. In bunkers inhabited for prolonged periods, large amounts of ventilation or air conditioning must be provided. Bunkers can be destroyed with powerful explosives and bunker-busting warheads.

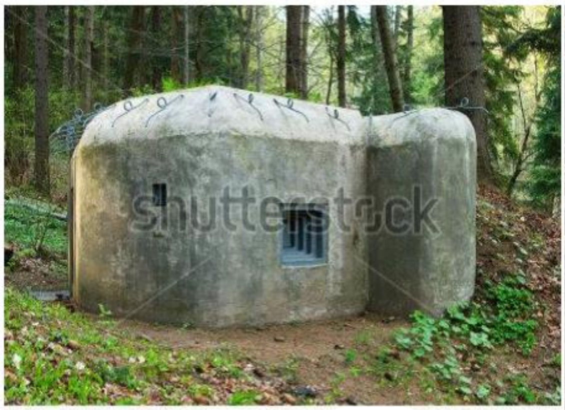


Fig.1 Military Bunker

Fig.2 Shipping container bunker

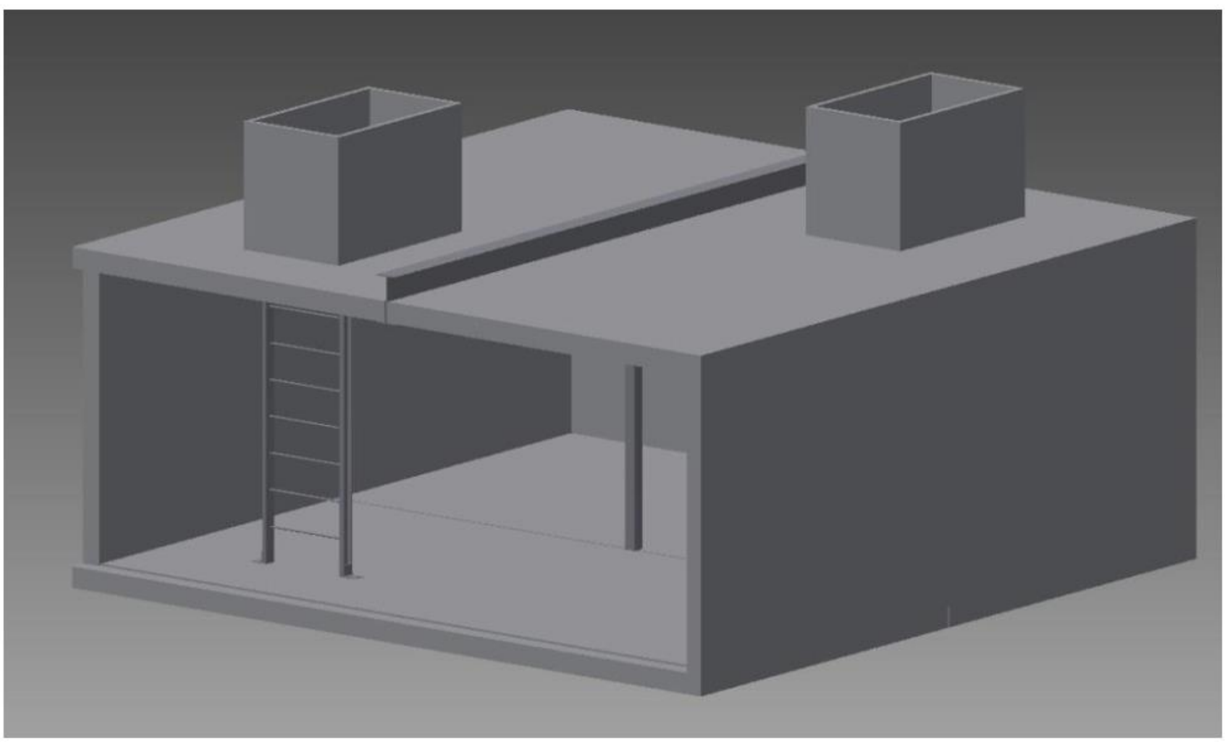


Fig.3 Concrete Bunkers with prestressed precast panel.

CODAL PROVISIONS

All the designs have been based on the recommendations of I.S 4995 -1974 and I.S 456 – 2000 codes.

DESIGN CONSIDERATION

The design process for bunkers is of two types – functional and structural, functional design must provide for adequate volume, proper protection of the stored materials, and satisfactory methods for filling and discharge. Structural considerations are stability, strength and control (minimizing) of crack width and deflection.

Loads to be considered include the following

1. Dead load of the structure itself and items supported by the structure.
2. Live Load forces are taken based on the type of material stored.

Bin design procedures consist of four parts as follows

i. Determine the strength and flow properties of the bulk solid.
ii. Determine the bin geometry to give the desired capacity, to provide a flow pattern with acceptable flow characteristics and to ensure that discharge is reliable and predictable. Specialised mechanical feeder design may be required.
iii. Estimate the bin wall loads from the stored material and other loads such as wind, ancillary equipment, thermal, etc.
iv. Design and detail the bin structure. Before the structural design can be carried out, the loads on the bin must be evaluated. Loads from the stored material are dependent, amongst other things, on the flow pattern, the properties of the stored material and the bin geometry while the methods of structural analysis and design depend upon the bin geometry and the flow pattern.

The importance of Stages i and ii of the design should not be underestimated. Simplified rules for the functional design of bins and for estimating wall loads are given in IS 4995-1974.

Design Example

Design the reinforcements for a concrete bunker to the following particulars:

Breadth of Bunker =5.35m

Depth =1.2m

Clear span =5.35m

Angle of repose for coal =35°

Use M20 grade concrete

Fe 415 HYSD bars.

Solution

Volume of bunker

Dimension of bunker

Adopt a bunker size 5.35x5.35x2.5m with the depth of 1.2m hopper bottom. Height of surcharge $=\frac{a}{2}\tan\emptyset=\frac{5.35}{2}\tan 35^\circ$

=1.87m.

Check for volume:

Volume of surcharge = $\frac{1}{3}a*b*h$

$V_1=\frac{1}{3}5.35*5.35*1.87$=17.5m^3.

Volume of cylindrical portion = a*b*h.

V_2=5.35*5.35*2.5=71.42 m^3.

Volume of hopper bottom portion, V_3

$V_3=\frac{1}{3}\left(ab+c^2+\sqrt{ab}+c^2\right)$

$=\frac{1}{3}\left((5.35^2)+0.5^2+\sqrt{5.35*5.35}+0.5^2\right)$

V_3=11.35 m^3.

V=100.27 m^3. ≈100 m^3.

As per IS 4995(part 1)-1974, table 1, the density of bituminous coal is 8kN/m^3 and angle of repose is 35°.

Design of Side walls

Horizontal working pressure p= whcos$^2\varphi$

p= 8*5.35 cos^{2}35=28.71 kN/m^2

Assume the thickness of side wall =230mm.

Effective span =5.35+0.23=5.58m.

L=B

Maximum bending moment at corners is

M=p (L^2+B^2-LB)/12 =p (L^2)/12 =(28.71*5.35^2)/12=68.47kNm.

Ultimate design moment, M_u=1.5*68.47

=102.72kNm.

Direct tension in wall,

T=pB/2 (for longer wall)

T=pL/2 (for shorter wall)

T=28.71*(5.35/2)=76.79kN.

Ultimate direct tension in wall, T_u

T_u=1.5*76.79=115.18kN.

Providing a cover of 30mm,

Providing effecting depth=230-30=200mm.

Distance between reinforcement of slap,

x=85mm. Net design moment = M_u-T_u*x

=102.72-(115.18*0.085)=92.93kNm.

Based on limiting moment resistance, effective depth required is given by

$D = \sqrt{\frac{M_u - T_u * x}{q * f_{ck} * b}} = \sqrt{\frac{102.72 - (115.18 * 0.085) * 10^6}{0.138 * 20 * 1000}}$
=183.5mm <200mm.

Since the depth provided is more. The section is under reinforced. Hence the area of steel required is,

$M_u = 0.87 f_y A_{st} d \{1 - A_{st} f_y / b d f_{ck}\}$
$92.93 * 10^6 = 0.87 * 415 * A^{st} * 183.5 \{1 - A^{st} * 415/1000 * 183.5 * 20\}$
$A_{st} = 1748.18 mm^2$.
Provide 12mm Φ bars,
$A_{st} = \frac{\pi * 12^2}{4} = 113 mm^2$.
Spacing $S = \frac{a_{st}}{A_{st}} * 100 = \frac{113}{1748.18} * 1000$
$= 64.6mm$
Hence provide 12mmΦ bars at 50mm c/c.

Positive bending moment at centre of span
$= p\frac{L^2}{8} - \frac{p(L^2 + B^2 - LB)}{12} = \frac{pL^2}{24} = \frac{28.71 * 5.35^2}{24}$
=34.23kNm.

Design ultimate moment=1.5*34.23=51.35kNm.
$M_u - T_u * x = 51.35 - (115.18 * 0.085) = 41.597kNm$
Hence the area of steel required to resist the moment is

$M_u = 0.87 f_y A_{st} d \{1 - A_{st} f_y / b d f_{ck}\}$
$41.597 * 10^6 = 0.87 * 415 * A^{st} * 183.5 \{1 - A^{st} * 415/1000 * 183.5 * 20\}$
$A_{st} = 680.15 mm^2$.

Provide 12mm Φ bars,
$A_{st} = \frac{\pi * 12^2}{4} = 113 \ mm^2$.
Spacing $S = \frac{a_{st}}{A_{st}} * 100 = \frac{113}{680.15} * 1000$
$= 166.13mm$

Provide 12mm Φ bars at 150mm c/c

Distribution reinforcement = 0.12%bD
$= 0.0012 * 1000 * 210 = 252 mm^2$.
Use 8mm Φ bars,
$a_{st} = \frac{\pi * 8^2}{4} = 50.26 mm^2$.
Spacing $S = \frac{a_{st}}{A_{st}} * 100 = \frac{50.26}{252} * 1000$
$= 199.46mm$
Hence provide 8mm Φ bars at 175mmc/c

Design of hopper bottom:

Weight of bituminous coal =
W=wV =8*100=800kN.

Weight of sloping hopper bottom (210mm) thick is computed as $W_h = (5.35 + 0.5/2)\sqrt{(2.425^2 + 1.5^2)} * (4 * 0.21 * 25$
=287.16kN.

Total load on 4 walls
=800+287.16=1087.16kN

Total load on one wall
=1087.16/4=271.79kN.
Then tanθ =1.5/2.425

$\Theta = \tan^{-1}$ (1.5/2.425)=31.74 and cosecθ=1.9

Direct tension in sloping wall = $W_t$cosecθ
= 340.71×1.9
= 565.58 × 58 KN

Working tension per meter run = 647.349 /5.35
=120.9 KN/m run

Design of ultimate tension = 1.5 × 120.9
= 181.499 KN
Area of reinforcement for resisting direct tension is,

A_{st} = (181.499×10^3) / (0.87 ×415)
= 502.69mm^2

Spacing S, = a_{st} / A_{st} × 100
= (120.9/502.69) ×1000
= 240.45 mm
Provide 12mm Φ bars @ 225 mm c/c in the direction of sloping faces

A_{st} = a_{st} / s × 1000
A_{st} = (120.9 / 225) × 1000
= 537.3.2mm^2

Normal component of coal pressure @ centre of slab is, $P_n = w.h_p [\cos^2 \theta + \cos^2 \varphi. \text{Sin}^2 \theta]$

Where,
W = 8 KN/m^2
h_p = [5.35 + (0.5 × 1.5) + (0.5 × 1.87)]
h_p = 6.95 m
$\theta = 37.07^\circ$ & $\varphi = 35^\circ$
$P_n = 8 \times 6.95 [\cos^2 37.07 + \cos^2 35. \text{Sin}^2 37.07]$ = 48.78 KN/ m^2

Working pressure = P_n = 848.78 KN/ m^2
Normal component due to weight of sloping slab,
= wd. cos θ
= 0.21 × 25 cos 37.07
= 4.19 KN / m^2
Total normal pressure P = P_n + wd. Cos θ
P = 48.78 + 4.19
P = 52.97 KN / m^2

Effective Design moment, L_1 = ((5+0.5) / 2) + 0.21 = 2.96m

Maximum negative bending moment, M
= P. ($L_1{}^2 + B_1{}^2 - L_1B_1$)/12
=$pL_1{}^2$/12=52.97*2.96^2/12=38.67kNm

Ultimate design moment=1.5*38.67
=58kNm.

Limiting moment of resistance, $M_{u\ limit}$
=0.138$f_{ck}bd^2$=0.138*20*1000*176.65^2.
=86.13kNm>58kNm.

Since M_u<M_{ulimit}

The section is under reinforced section.
M_u=0.87$f_yA_{st}d$ {1-$A_{st}f_y/bdf_{ck}$}
58*10^6=0.87*415*A^{st}*183.5{1-A^{st}*415/1000*183.5*20}
A_{st}=985.15mm^2.

Provide 12mm Φ bars,
$A_{st} = \frac{\pi * 12^2}{4} = 113$ mm^2.

Spacing $S=\frac{a_{st}}{A_{st}}*1000=\frac{113}{985.15}*1000$
$=114.7mm$

Provide 12mm Φ bars at 100mm c/c

Maximum positive bending moment at centre is = P. $(L_1{}^2 +\text{-}2B_1{}^2 +2L_1B_1)/12 = (52.97*2.725^2)/12=32.77kNm$

Ultimate bending moment =

1.5*32.77 =49.17kNm.

Area of reinforcement steel required is

$M_u=0.87f_yA_{st}d\ \{1-A_{st}f_y/bdf_{ck}\}$

$49.17*10^6=0.87*415*A^{st}*183.5\{1-A^{st}*415/1000*183.5*20\}$

$A_{st}=810.6mm^2$.

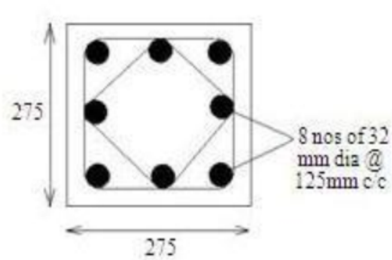
Provide 12mm Φ bars,
$A_{st}=\frac{\pi*12^2}{4}=113$ mm^2.

Spacing $S=\frac{a_{st}}{A_{st}}*1000=\frac{113}{810.6}*1000$
$=139.4mm$

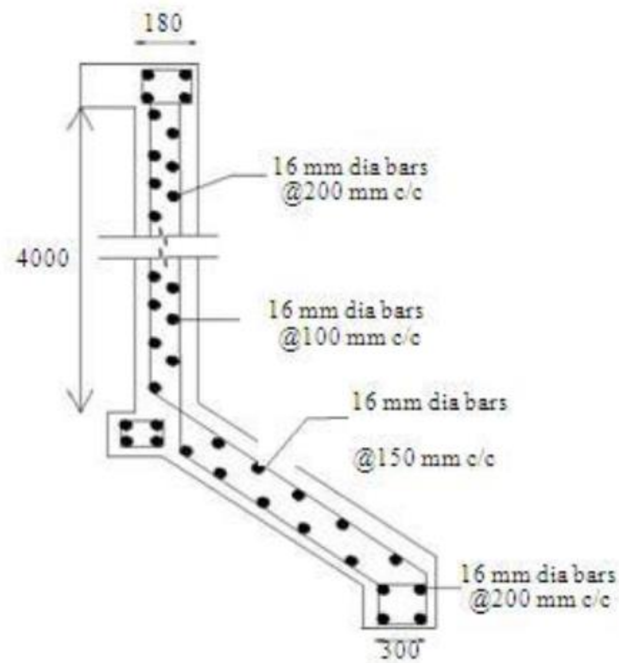
Edge beams

Provide edge beams of 300x300mm connecting the corner columns as the top and the junction of vertical walls and sloping slab with 4 numbers of 12mm Φ bars.

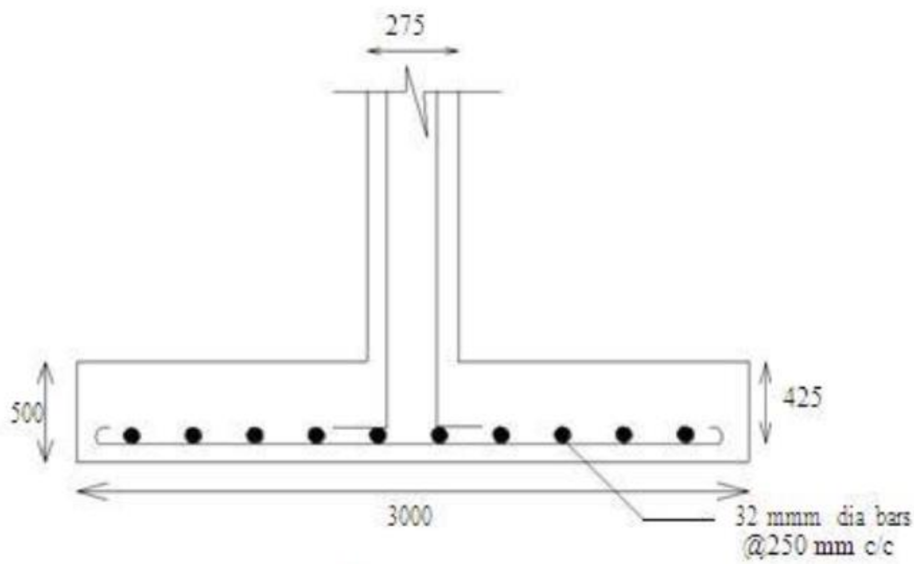
REINFORCEMENT DETAILING



Column details.



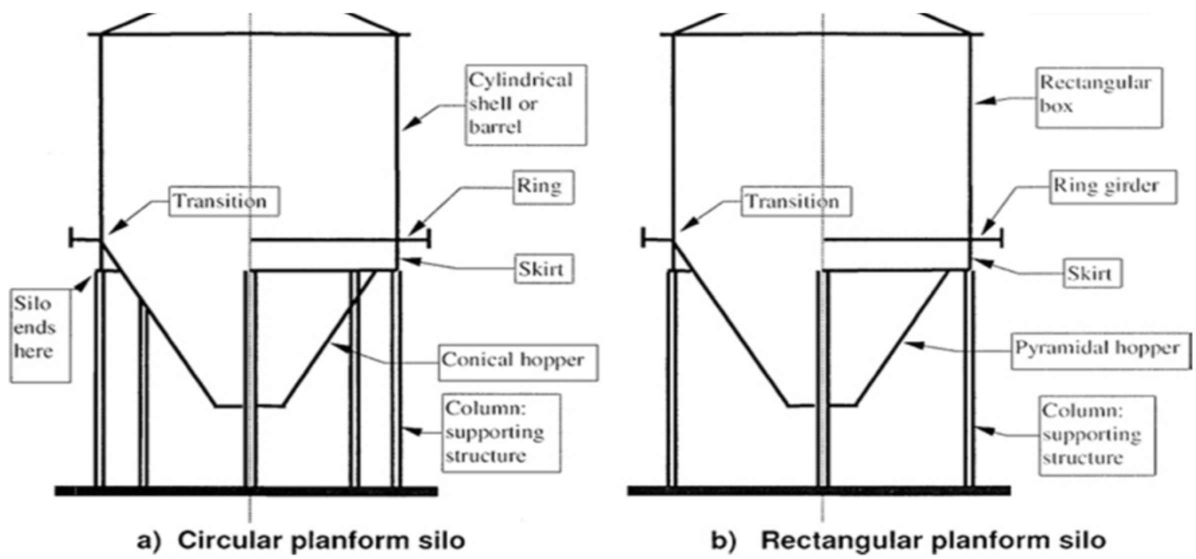
Bunker reinforcement details



Foundation details.

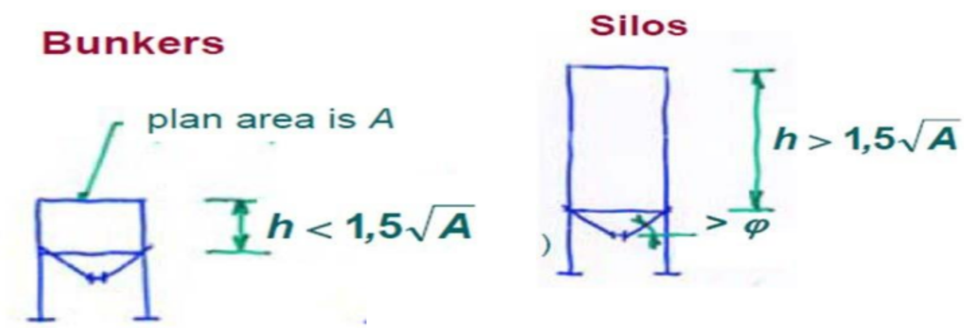
Silos

Silos are used by a wide range of industries to store bulk solids in quantities ranging from a few tones to hundreds or thousands of tones. The term silo includes all forms of particulate solids storage structure,that might otherwise be referred to as a bin, hopper, grain tank or bunker. They can be constructed of steel or reinforced concrete and may discharge by gravity flow or by mechanical means. Steel bins range from heavily stiffened flat plate structures to efficient unstiffened shell structures. They can be supported on columns, load bearing skirts, or they may be hung from floors. Flat bottom bins are usually supported directly on foundations.



Terminology used in silo structures

Difference between bunkers and silos



Types of silos

- Flat Bottom silos
- Hopper silos
- Truck load silos

Flat Bottom silos: Used for long-term storage of large quantities of grain, seeds and granular products

Hopper silos: Storage of grains (cereals, seeds, legumes, industrial products and other products) that require special storage conditions

Truck load silos: Are used for the storage and subsequent delivery of bulk products

Flat Bottom Silos

Hopper silos

Truck load silo

Actions

Temperature variation

Thermal contraction of a bin wall is restrained by the stored material. The magnitude of the resulting increase in lateral pressure depends upon the temperature drop, the difference between the temperature coefficients of the wall and the stored material, the occurrence of temperature changes, the stiffness of the stored material and the stiffness of the bin wall.

Consolidation

Consolidation of the stored material may occur due to release of air causing particles to compact (a particular problem with powders), physical instability caused by changes in surface moisture and temperature, chemical instability caused by chemical changes at the face of the particles, or vibration of the bin contents. The accurate determination of wall pressures requires knowledge of the variation with depth of bulk density and the angle of internal friction.

Moisture Content

An increase in the moisture content of the stored material can increase cohesive forces or form links between the particles of water soluble substances. The angle of wall friction for pressure calculations should be determined using both the driest and wettest material likely to be encountered. Increased moisture can result in swelling of the stored solid and should be considered in design.

Segregation

For stored material with a wide range of density, size and shape, the particles tend to segregate. The greater the height of free fall on filling, the greater the segregation. Segregation may create areas of dense material. More seriously, coarse particles may flow to one side of the bin while fine cohesive particles remain on the opposite side. An eccentric flow channel may occur, leading to unsymmetrical loads on the wall. The concentration of fine particles may also lead to flow blockages

Segregation patterns due to different mechanisms

Degradation

A solid may degrade on filling. Particles may be broken or reduced in size due to impact, agitation and attrition. This problem is particularly relevant in bins for the storage of silage where material degradation may result in a changing pressure field which tends to hydrostatic. Corrosion Stored material may attack the storage structure chemically, affecting the angle of wall friction and wall flexibility. Corrosion depends on the chemical characteristics of the stored material and also the moisture content. Typically, the design wall thickness may be increased to allow for corrosion and the increase depends upon the design life of the bin.

Abrasion

Large granular particles such as mineral ores can wear the wall surface resulting in problems similar to those described for corrosion. A lining may be provided to the structural wall, but care should be taken to ensure that wall deformation does not cause damage to the lining. The linings are usually manufactured from materials such as stainless steel or polypropylene.

Impact Pressures

The charging of large rocks can lead to high impact pressures. Unless there is sufficient material to cushion the impact, special protection must be given to the hopper walls. The collapse of natural arches which may form within the stored material and hold up flow, can also lead to severe impact pressures. In this case, a preventative solution is required at the geometric design stage.

Rapid Filling and Discharge

The rapid discharge of bulk solids having relatively low permeability to gasses can induce **negative air pressures** (internal suction) in the bin. Rapid filling can lead to greater consolidation, and the effects are discussed above.

Powders

The rapid filling of powders can aerate the material and lead to a temporary decrease in bulk density, cohesiveness, internal friction and wall friction. In an extreme case, the pressure from an aerated stored material can be hydrostatic.

Wind Loading

Design against wind loads is especially critical during bin construction.

Dust Explosions

Bins storing materials may explode should either be designed to resist the explosion or should have sufficient pressure relief area.

Differential Settlements

Large settlements often occur as bins are filled, particularly the first time. The effects of differential settlement of groups of bins should be considered. Differential settlements may lead to buckling failure of membrane steel bins.

Mechanical Discharge Equipment

Mechanical discharge equipment can lead to unsymmetrical pressure distributions even when it is considered to withdraw the stored material uniformly.

Roof Loads

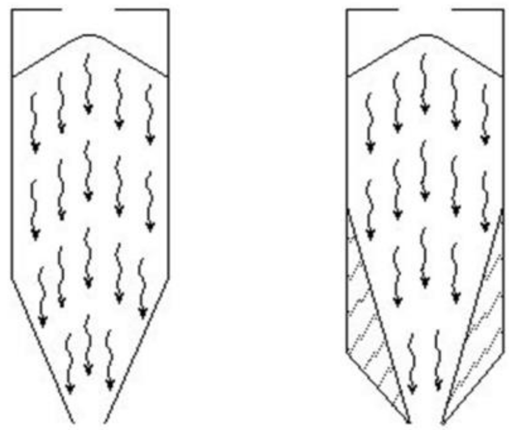
Bin roofs impose an outward thrust and axial compression on bin walls and should be considered during wall design. The design of bin roofs is beyond the scope of this lecture.

Silo design

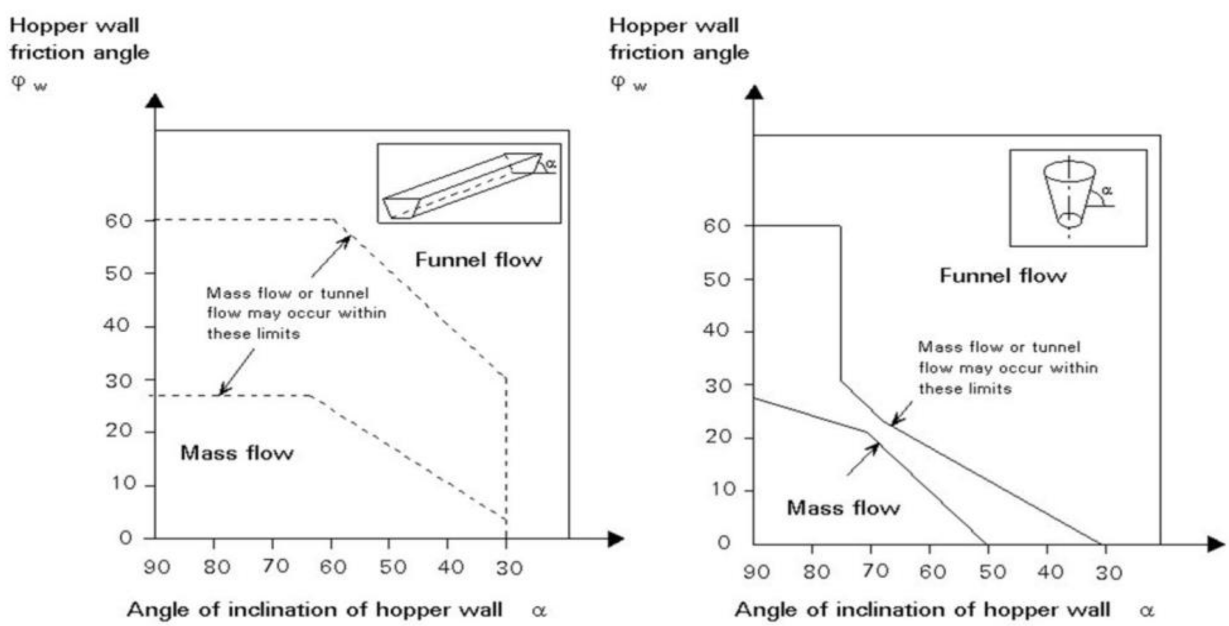
- The design of bins and silos to store bulk solids involves bulk material, geometric, and structural considerations.
  - Bulk material considerations are important because the frictional and cohesive properties of bulk solids vary from one solid to another, and these properties affect material behavior considerably.
  - When considering the geometric design of a silo, potential problems include arching

across an outlet, ratholing through the material, and the flow pattern during discharge.

- Established design procedures include selection of the optimum hopper angles and minimum outlet dimensions. The ideal discharge mode is one where, at steady state, all material flows without obstruction. This is referred to as mass flow. The discharge mode where only some of the material flows is called funnel flow.



MASS FLOW FUNNEL FLOW



Graphical method for the determination of flow pattern

Failure of silos

The major causes of silo failures are due to shortcomings in one or more of four categories:

- Failure due to design
- Failure due to construction
- Failure due to usage
- Failure due to maintenance

Failure due to design

The designer must first establish the material's flow properties and design criteria, including load combinations, load paths, primary and secondary effects on structural elements, and the relative flexibility of the elements.

Failure due to construction errors

In the construction phase, there are two main problems that can cause potential failures:

The more common of these is poor workmanship. Faulty construction,such as using the wrong materials and uneven foundation settlement are two examples of such a problem. Uneven settlement is rare but when it does occur, the consequences can be catastrophic since usually the center of gravity of the mass is well above the ground. The other cause of construction problems is the introduction of badly chosen, or even unauthorized, changes during construction in order to expedite the work or reduce costs.

Failure due to usage

Problems can arise when the flow properties of the material change, the structure changes because of wear, or an explosive condition arises. If a different bulk material is placed in a silo than the one for which the silo was designed, obstructions such as arches and ratholes may form, and the flow pattern and loads may be completely different than expected

Failure due to improper maintenance:

Maintenance of a silo comes in the owner's or user's domain, and must not be neglected. Two types of maintenance work are required:

The first is the regular preventative work, such as the periodic inspection and repair of the walls and/or liner used to promote flow, protect the structure, or both. Loss of a liner may be unavoidable with an abrasive or corrosive product, yet maintaining a liner in proper working condition is necessary if the silo is to operate as designed. The second area of maintenance involves looking for signs of distress (e.g., cracks, wall distortion, tilting of the structure) and reacting to them. If evidence of a problem appears, expert help should be immediately asked.