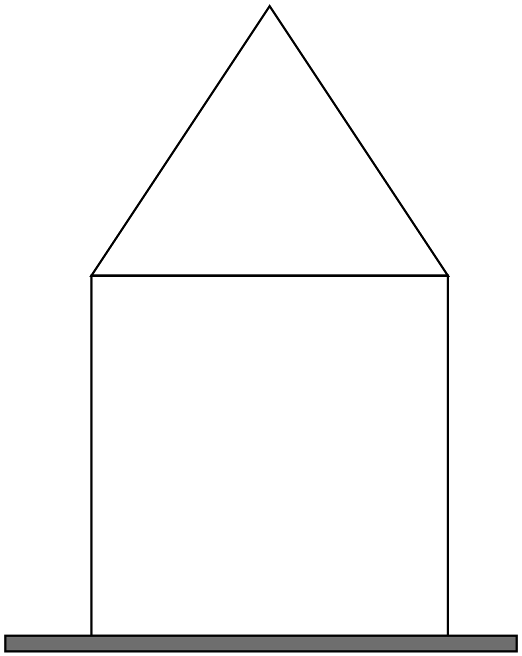
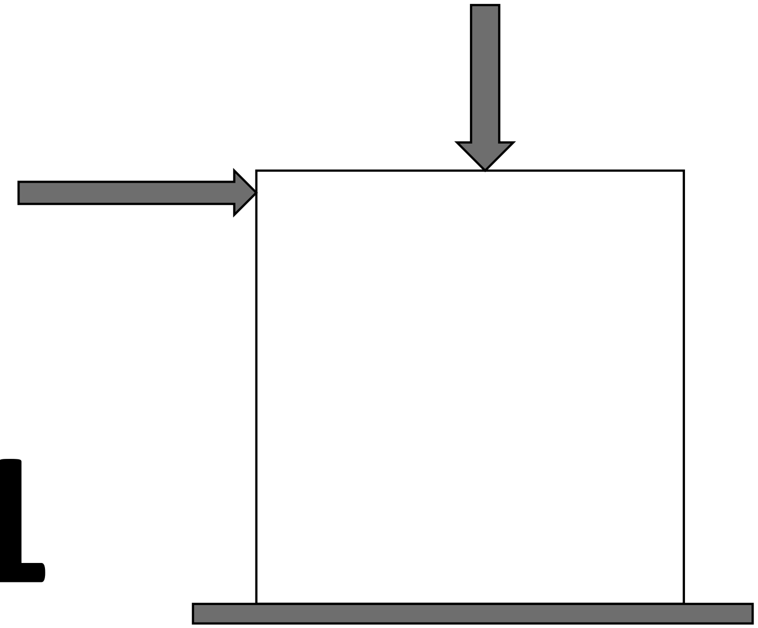
Industrial Structure (MCE-367)
Unit-1 & 2
Syllabus:
Unit-1: Planning of industrial structures,
Unit-2: Design of single and multi bay industrial structures in steel and concrete, Bunkers and silos

Name of Faculty: Madan Chandra Maurya

Asst. Professor, CED, MMMUT Gorakhpur.



Unit-1



Planning of industrial structures:

Factors to be Considered in Planning Factory Building:

Factory building should be designed only after a complete production plan, plant layout and equipment sequences are determined so that the building exactly fits the production needs of the plant. It is necessary to keep in mind all factors that may affect the functioning of the plant in the building.

Factors to be Considered in Planning Factory Building

Some of the important considerations in planning factory buildings are as follows:

1. Nature of Manufacturing Process

- The type of manufacturing process is the main determinant of plant buildings. The floor load, head space, bay size etc., depend on the type of machines and equipment to be used.

2. Plant Layout

- The arrangement of machines, service centres and office exercise considerable influence on the design and construction of plant buildings. In fact, labour pattern should be determined first and the building should be just a shell around this design. However, provision for flexibility should be made to meet the future needs.

3. Space Requirements

- The size of plant buildings depends upon space requirements for the flow and storage of materials, for location of machines, for service centres and for movement of employees. The height of the ceiling depends upon the type of equipment used. Use of overhead conveyors and tall equipment may require high roofs. But special structures and additional costs may be involved. Pits may be dug, if possible, to accommodate all equipment.

4. Material Handling

- Ease in material handling assists in the reduction of manufacturing cycle time, avoids production bottlenecks and reduces material handling cost. Cranes, conveyor belts hoists, etc., are increasingly used for easy handling of materials. A reduction in the number of columns and the maintenance of the ceiling at a desirable height are significant to the use of material handling equipment. It is evident that the requirements of efficient material handling equipment affect the building design. Conversely, the characteristics of the factory building affect a firm’s ability to use this equipment efficiently.

5. Plant Protection

- The building should be so designed that there is adequate protection of plant from fire, theft, etc. Sprinkler system, fire escape exits, automatic alarms, outdoor hydrant, safety lights etc., may be used for this purpose.

6. Lighting

- Lighting and illumination system within the plant exerts a significant influence on employees’ productivity and fatigue. Therefore, lighting standards should be kept in view during plant planning.

7. Heating, Ventilation and Air Conditioning

- It is quite common in large plants to provide separate structures for accommodating high pressure boilers. Their size will depend on heating requirements for production. Proper ventilation is necessary to provide adequate fresh air. Some manufacturing processes require considerable ventilation or controlled temperature and humidity. Air conditioning is particularly common in factory and other offices. Increasing costs of energy have led to new trends in heating, lighting and air conditioning. The statutory requirements of the Factories Act should also be met.

8. Service Facilities

- Facilities relating to cooling towers, emergency power, compressed air, sewage treatment, etc., should also be considered in plant building. Waste disposal should be such that regulations regarding air and water pollution, etc., are not violated.

9. Accessibility

- The factory building should be designed to ensure free movement of workers in the plant.

10. Aesthetic Considerations

- Efforts should be made to make the building a pleasant place to work for the employees. Their comfort should receive top priority as they spend a great deal of their total working hours in the factory. The building should have an elegant appearance as this adds to the pride and prestige of the employees and the management. Any attractive, well designed plant promotes community goodwill. It also has an influence on employees' morale. Such a plant projects the progressive outlook of the organization. It is heartening to note that some managements have paid special attention to this factor at present requirement.

11. Appearance

- The architectural style and building materials should be designed to give an attractive exterior to plant buildings. A pleasing appearance, good landscaping and clean surroundings are important to the local community.

12. Future Expansion

- Future expansion needs should be considered in planning a factory building. If multi-storied buildings are to be expanded with additional floors, it must be planned in advance so that the original structure has sufficient footing to bear the additional weight.

13. Fire Protection

- Need and importance for a fire protection system should be taken into account while planning for a factory building. This has become mandatory at present. Fire protection systems vary from the conventional fire extinguishers to automatic fire detectors and fire protection devices in industries.

14. Environmental Protection

- Need to protect environment has to be considered while planning a plant layout. This is being vigorously advocated all over the world now. It has become statutory in India too. This includes ensuring greenbelt all around the factory, horticulture and effluent disposal and water/air treatment plant and wastage disposal schemes, etc.

15. Effluent disposal

- Wherever chemical processes are used like electroplating, tanneries, etc., effluent treatment of the discharged water has become mandatory. Hence a factory building has to be planned for an effluent disposal system.

16. Air supply

- While designing plan for a factory building, necessary care has to be taken for adequate Air supply. This can be obtained through adequate air compressors.

17. Contractors, consultants and collaborators

- It is desirable that the building work is entrusted to well known consultants, experienced in constructing industrial buildings. The design of the factory and its layout also depends on the recommendation of collaborators — Indian and foreign when projects are executed as per technical collaboration from such parties.

18. Cost-economics

- This is the most important aspect of a building. Better management planning and effective monitoring by use of modern managerial aids like PERT/Milestones can bring down the cost of construction considerably. Normally, the cost of construction goes up due to delay in execution, changes in drawing, interruption of work during construction, deletions of the original design.
- Another source of wasteful expenditure is due to poor planning and procurement of materials, use of inferior quality materials and lack of effective supervision. So a factory building plan has to take into account of all cost factors.

Unit-2

Design of single and multi-bay industrial structures in steel and concrete:

https://law.resource.org/pub/in/bis/S03/is.sp.40.1987.pdf

http://docshare01.docshare.tips/files/23421/234217378.pdf

Introduction:

Bunkers and silos are structure that are used as storage tanks. Structural design of bunkers with procedure and design considerations are discussed.

The bunkers and silos made of reinforced concrete have almost replaced the steel storage structures. Concrete bins possess less maintenance and other architectural qualities greater than steel storage tanks. They are used to store materials like grain, cereals, coal cement etc. They both serve the purpose of bins.

Difference between Bunker and Silo

Silos are structures built for storing different materials. On the other hand, Bunkers are underground dwellings, normally used in war. The main differences between a Bunker and a Silo structure is given below-

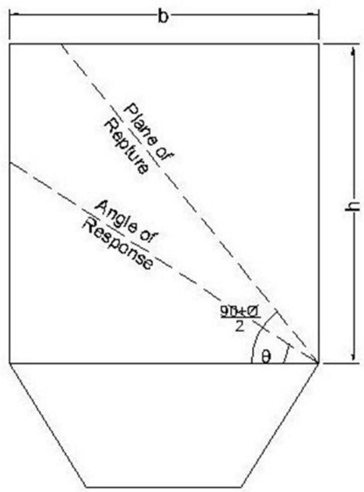


Fig: Binker

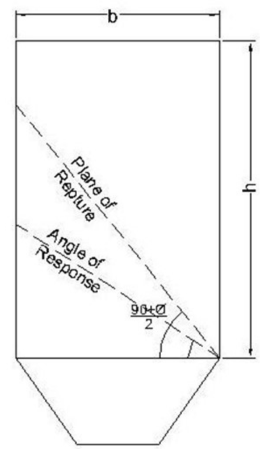


Fig: Silo

1.	**Bunkers are shallow structures.**	**Silos are tall structures.**
2.	Plane of rupture meets the top horizontal surface.	Plan of rupture meets the opposite side of the structure.
3.	The total load of material is supported by the floor of the bunker.	Only a fraction of the total load of material (due to side wall friction) is supported by the floor of the silo.
4.	The intensity of horizontal pressure on the sidewall is determined by Rankine's Theory.	The intensity of horizontal pressure on the sidewall is determined by Janssen's Theory.
5.	Bunkers are normally metallic with less storage capacity	Silos are normally built by concrete

Concept and difference between bunkers and silos are explained in the following sections:

Bunkers are mainly employed for storage of underground dwellings. These are mainly related to emergency conditions during wars. The main two characteristics that make a bin to act as a bunker is based on the

- Depth (H)
- Angle of rupture

These are characterized as shallow structures. The angle of rupture of the material in case of bunkers, will meet the horizontal surface at the top of the bin, before it touches the opposite side walls of the structure as shown in the figure-1. Bunkers may be circular or rectangular (or square) in plan.

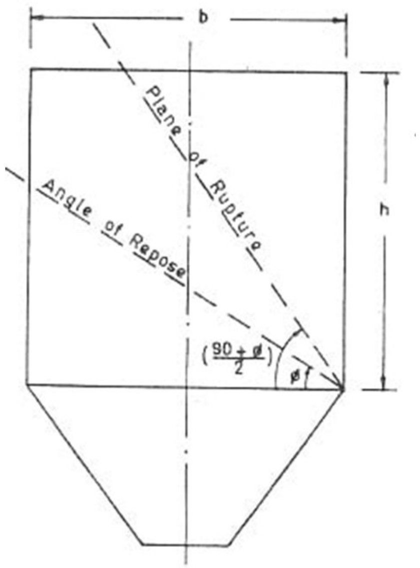


Fig.1: Sectional View of a Bunker

The angle of rupture is formed at $\left(\frac{90+\phi}{2}\right)$ from the horizontal as shown above. The angle ϕ is called as the angle of repose. The lateral pressure form the material is resisted by the side walls. The bunker floor takes up the total load of the material.

The theory used in determination of lateral pressure in bunkers is Rankine 's Theory.

Design Consideration of Bunkers

1. Design of Bunkers with Rectangular or Square Bottom

- The main structural elements that constitutes a bunker are shown in figure-2. They comprise of
- Vertical walls
- Hopper Bottom
- Edge Beam (At the top level)
- Supporting Columns

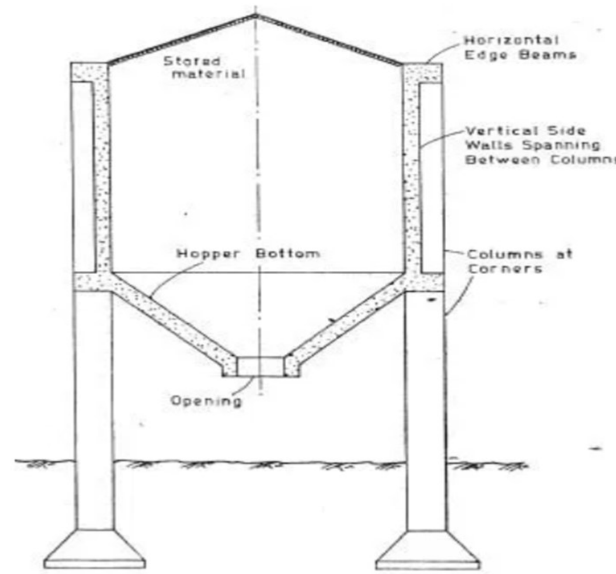


Fig.2: Structural Elements of a bunker

The design Procedure can be explained in following steps:

Step 1: Design of Vertical Walls

Based on Rankine's Theory, the lateral pressure applied on the vertical wall can be given by the formula

$$p_{\alpha} = w \,.\, h \,.\, \cos\alpha \left[\frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\Phi}}{\cos + \sqrt{\cos^2\alpha - \cos^2\Phi}}\right] \rightarrow \textbf{Equation-1}$$

Where, P_a = Lateral pressure intensity that is acting at a height of 'h'.

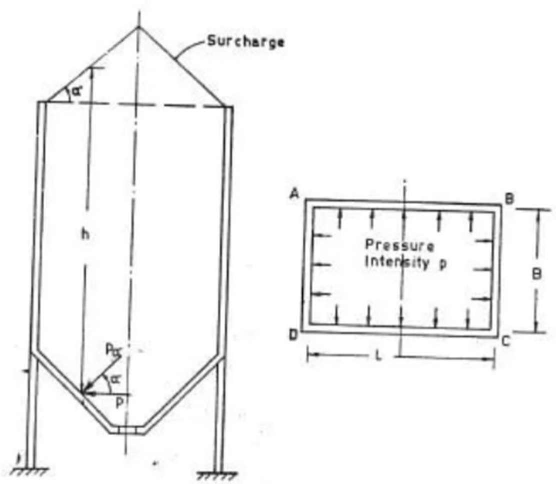
L = Length of the bunker

B = Breadth of the bunker

a = Angle of surcharge (The material slope as shown in figure-3)

= Angle of rupture

w = density of the material stored in the bunker



This pressure p_a is acting in the direction parallel to angle of surcharge. So, the pressure that is applied on the vertical walls are the horizontal component of p_a. Let it be p as shown in figure-3.

Hence $p = p_\alpha . \cos \alpha$

When $\alpha = \Phi$;

Equation-1 Becomes, $p_\alpha = w.h.\cos \Phi$;

Hence $p = w.h.\cos^2\Phi$ →**Equation -2**

Fig.3: Representation of angle of surcharge (?) and pressure component acting on walls (p).

Design Moments:

a) Negative Moments at the supports

$$M_A = M_B = M_C = M_D = -\frac{P}{12}[L^2 + B^2 - BL]$$

b) Positive Bending Moment at the center of longer sides (AB or CD)

$$= \frac{PL^2}{8} - \frac{P}{12}[L^2 + B^2 - BL]$$

c) Positive Bending Moment at the center of shorter sides (BC or AD)

$$= \frac{PB^2}{8} - \frac{P}{12}[L^2 + B^2 - BL]$$

Direct Tension:

a) Tension in long walls $= (\frac{pB}{2})$

b) Tension in Short walls $= (\frac{pL}{2})$

Effective depth:

The effective depth is given by the formula

$$d = \sqrt{\frac{M - T.x}{Q.b}}$$

$$A_{st} = (\frac{M - T.x}{\sigma_m .j.d}) + (\frac{T}{\sigma_m})$$

To resist maximum bending moment adequate thickness should be provided. The reinforcement details are provided for the vertical walls based on the maximum bending moments and the direct tension design values.

- The reinforcement obtained from above equation (A_{st}), is arranged in the horizontal direction. Minimum distribution reinforcement is provided in the vertical direction.
- Minimum cross section of 300mm x 300mm edge beams are provided at the top, to facilitate attachments used by conveyor supports.

Step 2: Design of Hopper Bottom

- The hopper bottom is designed for direct tension caused due to:
- a) Self weight of the material
- b) Self weight of sloping slab

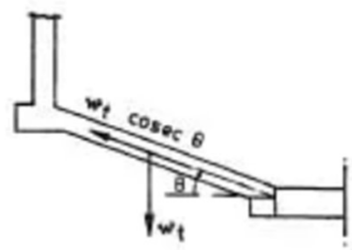


Fig. 4: Sloping slab in the hopper subjected to direct tension

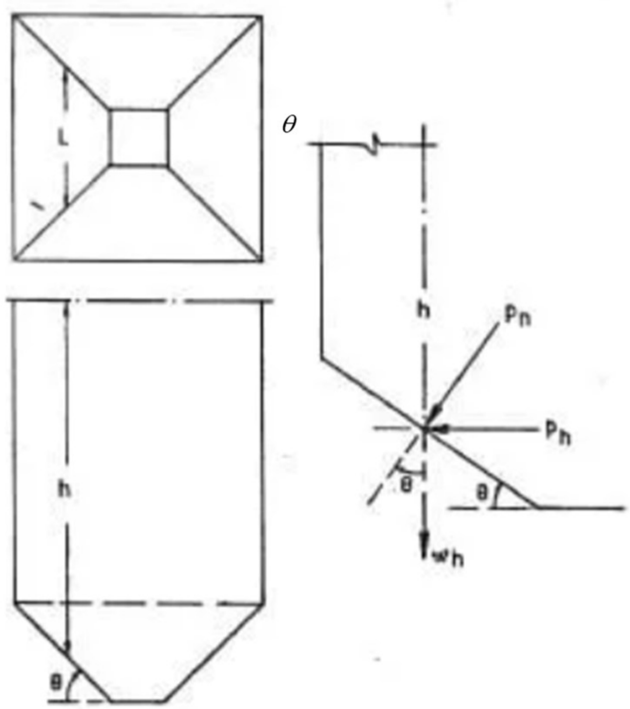


Fig.5: Sloping Slab in Hopper Bottom Subjected to bending

From figure-4 and 5,
wt = weight of material

Calculation of Direct tension

$$= Wt \, . \, cosec \, \theta$$

Where, θ is the angle between the horizontal and the sloping slab.

Calculation for Bending Moment:

To determine the maximum moments at the supports and the center of the sloping slab, we need to determine the normal pressure intensity which is the sum of normal pressure due to material weight and the self-weight of the slab

- **a) Due to material weight**
- If *w* = density of the material
- *h*= average height at the center of the slope of bottom
- *L* = Effective span at the center of the slope, as shown in figure-5
- Then, Normal pressure intensity for depth h is

$P_n = \text{ph}\cos^2\theta + \text{wh}\cos^2\theta$

(put, $\text{ph} = \cos^2\Phi$ from equation-2)

hence after rearranging,

$$p_n = wh\,[\,cos^2\theta + cos^2\Phi.\ sin^2\theta]$$

b) Due to self-weight of slab

Let W_d be the self-weight of slab

Its normal component with respect to plane of slab is given by,

$$= W_d \, . \, cos\theta$$

Hence total normal pressure intensity is given by,

$$P = (p_n + W_d \, . \, cos\theta)$$

Hence, Maximum Negative Bending Moment at Supports $= \frac{PL^2}{12}$

Positive Bending Moment at the Center $= \frac{PL^2}{24}$

2. Design consideration of Bunkers with Circular Bottom

For design of bunkers with circular cross section, vertical walls are subjected to a hoop tension along the diameter of the bunker. The value of hoop tension is given by the formula $T_h = 0.5p_h .D$

- D = Diameter of the bunker
- p_h = horizontal component of pressure at a depth *h* from the top
- The reinforcement details are provided to resist the hoop tension for this a minimum thickness of 120mm is recommended.
- The hopper bottom is designed for both direct and hoop tension due to normal pressure on the sloping slabs.
- Minimum vertical reinforcement is provided based on the bar used.

Step 3: Design of Columns

Columns are designed for compression and bending. The loads on the columns are due to:

a) Vertical loads = weight of stored material + self-weight of members

b) Horizontal loads = Wind Loads

http://egyankosh.ac.in/bitstream/123456789/31116/1/Unit-13.pdf

Design of Silo:

About Silos:

- From the structural point of view, if the plane of rupture of the material stored—drawn from the bottom edge of the bin—does not intersect the free surface of the material stored, the bin is known as a silo.
- Conversely, if the rupture plane—drawn from the bottom edge of the bin—intersects the free surface of the material stored, the bin is termed a bunker.
- According to the Eurocode 1, the geometrical limits applicable for silos are $h1/d < 10$, $h1 < 100$ m, $d < 50$ m (where h1 = height; d = diameter). Given these limitations, silo is defined as a slender silo if $h1/d > 1.5$ or a squat silo if $h1/d \leq 1.5$.

Common forms:

- Silos are generally circular in cross section, although different forms, such as square or rectangular cross sections are commonly adopted for shallow bins or bunkers.
- When calculating the size of a silo of a specified capacity, the unit weight of the material should not be overestimated and too small a value should not be assumed for the angle of internal friction.

Table 1 Unit Weight and Angle of Internal Friction of Some Commonly Used Materials

Materials	Unit weight (kN/m^3)	Angle of internal friction (Φ) in degrees
Wheat	8.50	28°
Paddy	5.75	36°
Rice	9.00	33°
Maize	8.00	30°
Barley	6.00	27°
Corn	8.00	27°
Sugar	8.20	35°
Wheat flour	7.00	30°

Material

- The materials generally used for the construction of silos are structural steel and reinforced concrete.
- Both materials have their own merits and demerits.
- A silo having a circular cross section may also be formed with thin-walled plates without any stiffener.

Structural Responses:

- Concrete silos

High strength, durability, workability, long life, and resistance to fire may be considered as the main properties of the concrete silos.

- Steel silos

On the other hand, because the steel members have high strength, the steel silos can resist high loads with comparatively lighter weight and smaller-sized members.

The steel silos are gas- and water-tight because of higher density. Fabrication, erection, and handling or dismantling are easier. However, the main drawback with steel is that it is susceptible to corrosion.

Bottom structure

• For the design of their bottoms, silos may or may not have premises underneath the bottom. The choice of the type of silo depends first on the properties of the loose material and in the unloading equipment selected. Materials

• Some of the materials that require storage in silos are hygroscopic and, in contact with moist air, cohesion builds up to such a degree that the material can be loosened only by mechanical means. Raw sugar, salt, and some granular materials fall in this category.

• Flour is also hygroscopic, but in relatively dry storage the cohesion is weak, and the material can be easily loosened by compressed air so that it flows out of the cells by gravity.

• Non-hygroscopic or less hygroscopic materials are stored most economically in relatively high cellular silos the individual cells of which are emptied by gravity flow.

- Also some of the highly hygroscopic materials (sugar, salt, etc.) may attack concrete, so that a protective coating for the inside surfaces of walls is required unless special cement and dense, closed surfaces are used.
- If hygroscopic sticky materials are not dried before storage, considerable cohesion and arching can be expected; consequently, the cell walls are subjected to unsymmetrical loading during emptying and have to resist considerably higher horizontal pressure than in the fully-filled condition.
- Sometimes silos are required to be provided with driers and equipment for infected grain-treatment facilities.

Assessment of Forces: Pressure Theories:

- The stored materials in the storage bins exert horizontal pressure to the side walls of the bins in addition to the vertical forces from weight of the material.
- Pressure along the depth of the silo varies during the filling and emptying processes of the materials.

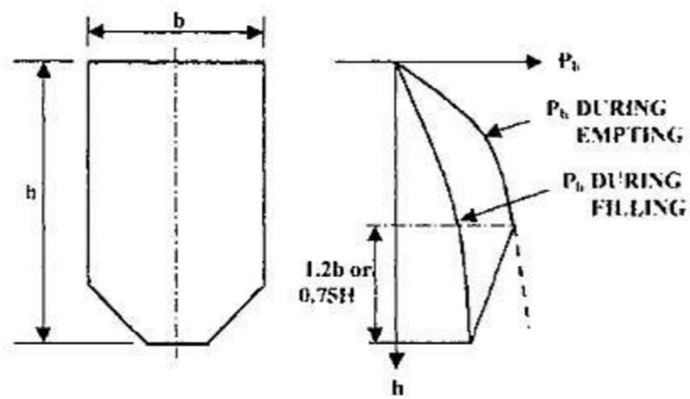


Fig. 5 Variation of pressure along the depth of a silo.

- Location of discharge opening may also substantially change the pressure distribution on the bin walls.
- Discharge through eccentrically loaded openings causes change in lateral pressure.
- The equilibrium of the contained material is changed while unloading the silo.
- If the silo is unloaded from the top, the frictional load on the wall may change owing to re-expansion of the material; however, the lateral pressures remain the same as those that occur during filling.
- When unloading a free-flowing material from the center of a hopper at the bottom, one of two different modes of flow may occur.

Mode of Flow:

• The mode of flow depends primarily on the nature of the contained material, and the size of the silo and the hopper.

• The modes are generally termed core flow and mass flow.

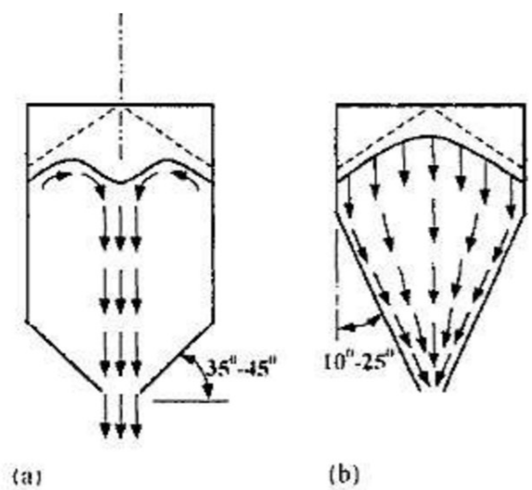


Fig. 6 Condition of flow of material: (a) core flow, (b) mass flow.

Core Flow: Core flow generally gives rise to some increase in lateral pressure from the filled condition.

Mass Flow: Mass flow occurs in silos with steep-sided hoppers. To ensure the convergent downward movement of the entire mass of the material as a whole, steep-sided hoppers are provided.

- However, this action produces substantial local increase in lateral pressure at the intersection between the vertical walls and the hopper bottom. Sometimes a situation may arise in which the flow may be a borderline between core flow and mass flow and, in the process, the stored material is intermittently in core or mass flow.
- This occurs when the hopper is almost—but not quite—steep and smooth enough for mass flow and leads to jerky flow.
- At high withdrawal rates, these jerks can be destructive.
- The volumetric change of the stored material owing to increase in moisture content and temperature fluctuations can cause the development of high pressures.

• In general, the factors that affect the pressure distribution are

i) moisture content of the stored material,
ii) particle size gradation,
iii) angularity of particles of the stored material,
iv) temperature of the material,
v) rate of filling,
vi) amount of aeration during filling,
vii) aeration during withdrawal, and so on.

• The horizontal pressures exerted by the material on the walls are calculated using Janssen's theory, Airy's theory.

• In Janssen's theory is considered for the calculations of pressure. The variation of vertical and horizontal pressure may be represented as

$$p_i(h) = p_i(\max)[1 - e^{-h/z_0}]$$

$$p_i(h) = p_i(\max)C$$

- Where pi(h) is the pressure at any height and pi(max) is the maximum pressure developed in the wall;

$$z_0 = R/(\mu' K);$$

$$C = [1 - e^{-h/z0}];$$

R is hydraulic mean radius and is obtained by dividing the plan area (A) of the silo by the plan perimeter (P); μ'is the coefficient of wall friction.

- K is the pressure ratio,

which generally lies between (1-sinΦ)/(1+sinΦ) and (1+sinΦ)/(1-sinΦ). However, the exact value of K is obtained experimentally.

• The acceptable values of K in different codes for broadly classified material according to the particle size (s) are as indicated in Table.

Table 2 Values of Pressure Ratio (K) and Angle of Wall Friction (Φ') of Different Material

Sl. No	Material	Pressure ratio (K) during		Angle wall friction (Φ') during	
		Filling (K_f)	Emptying (K_e)	Filling (Φ'_f)	Emptying (Φ_e)
1	Granular material $s \geq 0.2$ mm	0.5	1.0	0.75	0.6
2	Powdery material $s \leq 0.06$ mm	0.5	0.7	1.0	1.0

- Values of the maximum pressures (pv,ph,pw) during filling and emptying conditions are obtained in terms of unit weight, weighted perimeter, pressure ratios, and coefficient of wall frictions

Table 3 Values of Maximum Pressures During Filling and Emptying Conditions

Types of pressures	Maximum values of pressures during	
	Filling	Emptying
P_v	$\omega R / K_i \mu'_f$	$\omega R / K_e \mu'_e$
P_h	$\omega R / \mu'_f$	$\omega R / \mu'_e$
P_w	ωR	ωR

Guidelines for Analysis:

- The walls of silos are designed to resist bending moments and tension caused by the developed pressure of the stored material.
- In silos with circular cross sections, the circular wall is designed for the hoop tension, which is equal to (ph =d/2.0);

Where ph is the horizontal pressure exerted by the material and d is the diameter of the silo.

For Rectangular silo:

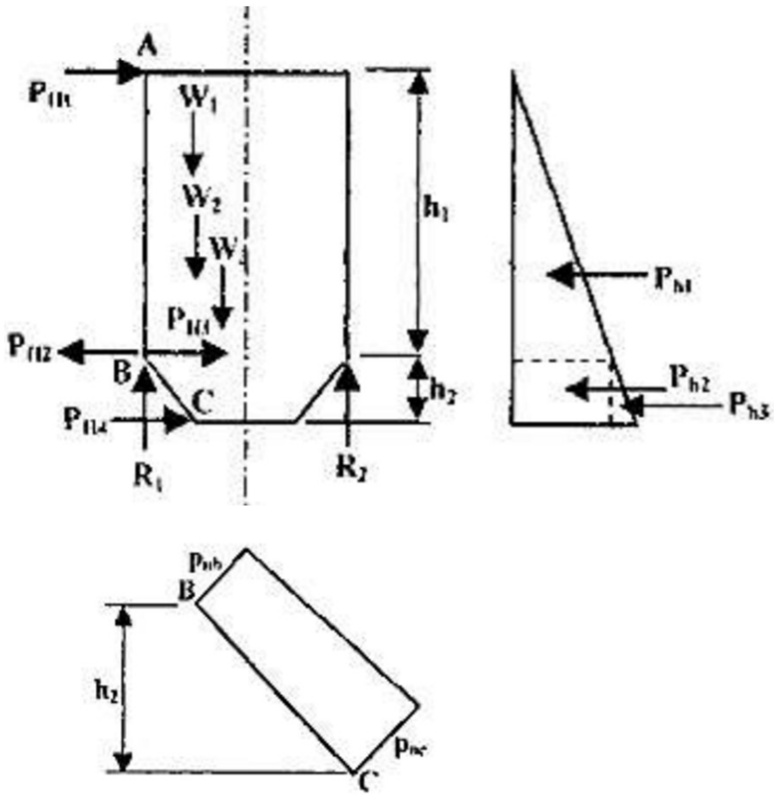
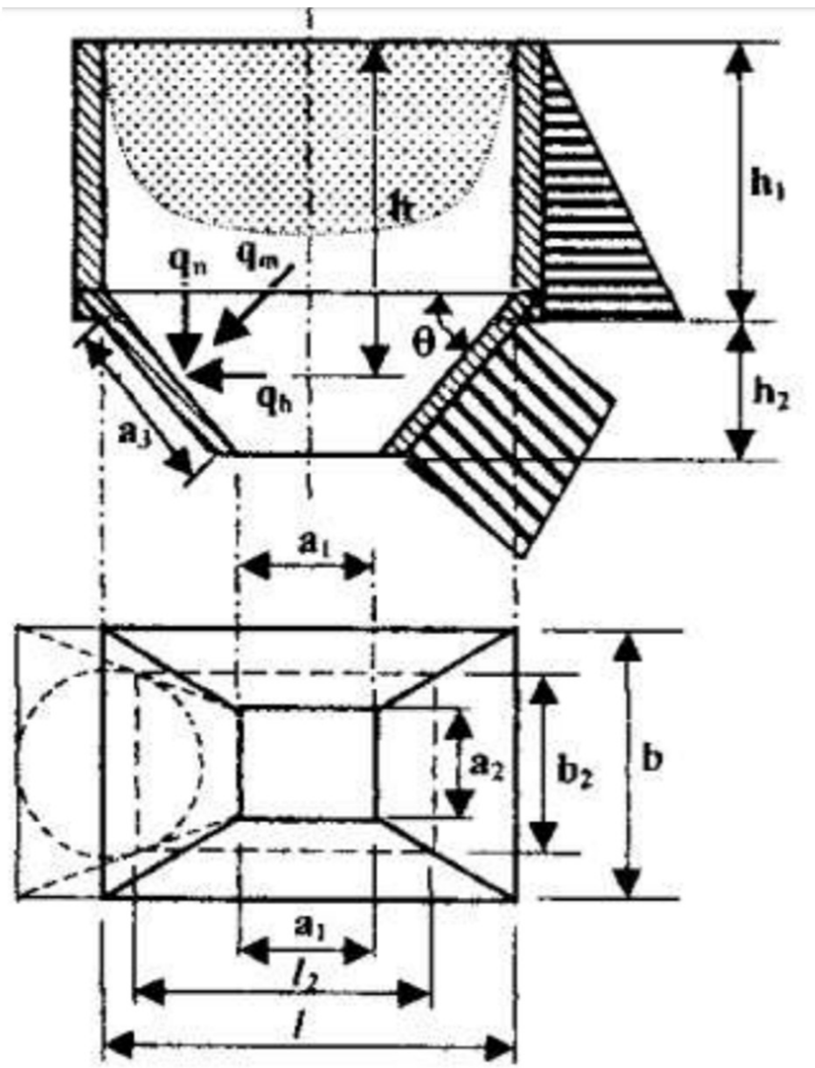


Fig. 8 Distribution of resultant pressure on walls.

- Combined bending and direct tension will occur if the walls are spanning horizontally
- if the walls are spanning vertically, bending is taken care of in the vertical direction,
- whereas direct tension is taken care of in the horizontal direction



• To finding the center of pressure, the intensity of pressure normal to the slope at this point, and the mean span.

• The bending moments at the center and edge of each slope are then calculated.

• A typical silo with a circular cross section consists of a cylindrical wall, top ring beam, bottom ring beam, and conical hopper. The capacity of the silo may be expressed in parametric form as

$$Q = \frac{1}{4}\pi d^3 Y$$

where

$$Y = (K_1 + 0.167 \tan \theta)$$

Hence,

$$d = \left(\frac{4Q}{\pi Y}\right)^{1/3}$$

Q- is the storage capacity of silo in cubic meters (m3); d- is the diameter of the silo in meters, K1- is a factor defined as the ratio of height to diameter (h1/d). Θ - is the inclination of the hopper bottom with the horizontal.

The recommended inside diameters of silos are : 1. For heavy grain (such as wheat): 6.0 m 2. For light grain (such as sunflower): 12.0–18.0 m

- The ring beams provided at the top and at the junction of a cylindrical wall and hopper part are primarily designed for the radial forces, which introduce hoop tension or compression.
- The vertical component of the loads at those levels are transferred to the wall or to the supporting system.
- Conical hoppers are essentially subjected to only meridional and hoop tensions.

Example 1. Select the diameter and height of a silo to store grains with a storage capacity of 500 m3. Assume the inclination of hopper bottom with horizontal as 30 degrees. As has been mentioned before\

Solution:

$$Q = \frac{1}{4}\pi d^3 Y$$

Where,

$$Y = (K_1 + 0.167 \tan \theta)$$

Assuming K1 (h1/d) as 4 and for θ=30° , the value of Y is 4.0964. Hence, the value of the diameter dis 5.375. If we adopt a diameter of 5.5 m, the height of the silo, excluding the hopper part, is 4 * 5.5 m = 22.0 m

Design of Component Parts:

Design of Silo Wall

1.For a steel silo,

• the thickness of plate is determined from consideration of the compressive and tensile stresses to which the wall will be subjected by the total vertical weight.

• The vertical weight includes weight of the material stored above that level, self weight of plate, and lining material.

• The total weight over the cross-sectional area yields compressive stress. The Poisson effect of compressive stress along with the hoop stress yields total tensile stress

2. For a concrete silo,

• the horizontal ring reinforcements are provided to take care of the tensile stresses, whereas vertical bars are provided to take care of compressive or bending stresses.

3. For silos with rectangular cross sections, • if the wall spans vertically, horizontal reinforcement is provided to resist the direct tension, and vertical reinforcement to resist the bending moments. The horizontal bending moments owing to the continuity at corners should be considered.

Design of the Hopper:

To provide the particular thickness of plate,

i. The total vertical load transferred at the hopper
ii. The longitudinal stress and
iii. the hoop stresses are calculated.

• If the stresses are within acceptable limits, the assumed thickness of the plate is adopted.

• The amount of horizontal reinforcement required for the hopper bottoms, provided in the form of an inverted truncated pyramid, is based on the horizontal direct tension combined with the bending moment.

Reinforcement Detailing:

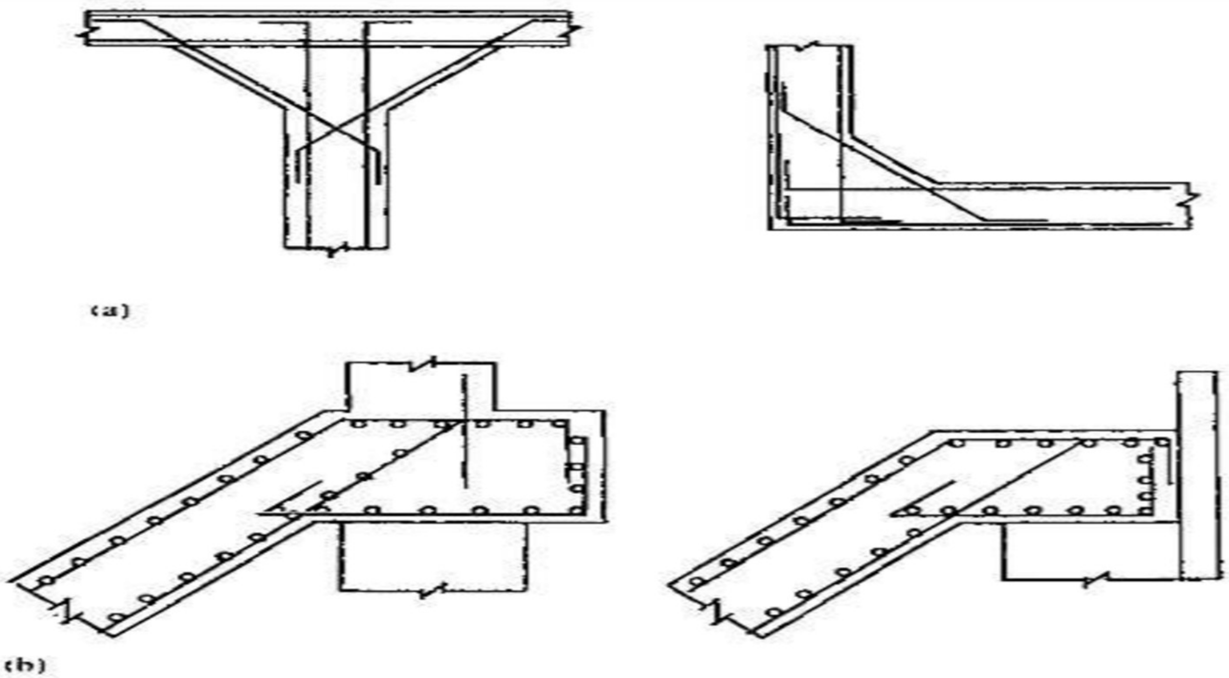


Fig. 10 Typical details for concrete silo: (a) reinforcement position at intersecting walls, (b) typical details of hopper-supporting beams.

References:

Books & References:

1. IS: 800 2007
2. 2. Limit State Design of Steel Structures - S. K. Duggal (TMH)
3. 3. Reinforced Concrete Structure, Volume II - B.C. Purnima (Lakshmi Publications)
4. SP 40 (1987): Handbook on Structures with Steel Portal Frames (Without Cranes).
5. IS 9178-2 (1979): Criteria for Design of Steel Bins for Storage of Bulk Materials, Part 2: Design Criteria [CED 7: Structural Engineering and structural sections]