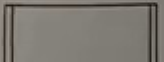
26

Bunkers and Silos

26.1. INTRODUCTION

Bunkers and silos are the structures used for the storage of materials like grain, cereals, coal, cement etc. Both bunkers and silos are commonly called as *bins*. If the depth and breadth of a bin are such that the plane of rupture meets the surface of the material, before it strikes the opposite side of the bin, it is called a *shallow bin* or a *bunker*. However, when the plane of rupture drawn from the bottom edge of the bin does not intersect the surface level of the material, it is called a *deep bin* or a *silo*. Ordinarily, a bin may be said to be a silo, if its depth is greater than twice the breadth. Hoppers are rectangular bins with the bottom floor consisting of four sloping slabs.

Silos are generally circular in cross-section. For self-cleansing and for emptying, it is supported on a number of columns, through a ring beam. Its bottom height is fixed in such a way that a truck can pass its underneath. It is covered with shallow spherical or conical dome, or with a beam and slab type flat roof with suitable man-hole.



The stored material exerts pres-

26.4. ...

In the bunkers, because of shallow depth, it is assumed t... the wall and the fill in negligible. Fig. 26.5 shows a bunker with ot... such as top rib, junction beam, hopper bottom with central opening, ...

(*a*) **Pressure and moments on walls**

Let α be the angle of surcharge of the fill. The pressure against the vertical wall is given by Rankine's formula:

$$p = wh \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}} \quad \text{...[26.16 (a)]}$$

The pressure acts in a direction parallel to the top surface of the retained material. The horizontal component is

$$p_h = p\cos\alpha = wh\cos^2\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}} \quad \text{...[26.16(b)]}$$

If $\alpha = \phi$,

$$p_h = wh\cos^2\alpha \quad \text{...[26.16 (b)]}$$

If $\alpha = 0$, (*i.e.* top surface ... horizontal),

$$p_h = wh \frac{1 - \sin\phi}{1 + \sin\phi} \quad \text{...[26.16(c)]}$$

... conditions are such ... top is

$$M_{CB} = \frac{p_h B^2}{8} - \frac{p_h}{12}(B^2 - BL + L^2) = \frac{p_h}{24}(B^2 + 2BL - 2L^2) \quad \text{...[26.18 (a)]}$$

and the positive moment at the centre of span L is

$$M_{CB} = \frac{p_h}{24}(L^2 + 2BL - 2B^2) \quad \text{...[26.18 (b)]}$$

In addition to the bending moment, the walls are also subjected to direct tension due to pressure on the adjoining walls. Thus, direct tension on wall L will be $0.5\ p_h \cdot B$ *and that on wall* B *will be* $0.5\ p_h \cdot L$. *Apart from the bending moment and direct tension, the walls are also subjected to vertical weight of material transferred to it by hopper bottom. The vertical wall is therefore designed as a deep beam supported between the columns.*

Circular bunkers. The vertical wall of the circular bunker of diameter b is designed for a hoop tension of $p_h \cdot b/2$.

26.5. HOOPER BOTTOM

(*a*) **Conical hopper.** Conical hoppers are subjected essentially to meridional and hoop tensions. The total meridional tension at any horizontal plane passing through the hopper is such that its vertical component is equal to total vertical pressure on the plane plus the weight of the hopper and contents below the plane. Consider any horizontal plane AD at depth h below the top surface of the material. Let W_g be the weight of the grain and W_c be the weight of the cone.

... are also subjected to vertical weight of material transferred to it by hopper bottom. ... wall is therefore designed as a deep beam supported between the columns.

... Circular bunkers. The vertical wall of the circular bunker of diameter b is designed for ... tension of $p_h \cdot b/2$.

... HOPPER BOTTOM

(a) **Conical hopper.** Conical hoppers are subjected essentially to meridional and ...op tensions. The total meridional tension at any horizontal plane passing through the ...pper is such that its vertical component is equal to total vertical pressure on the plane ...s the weight of the hopper and contents below the plane. Consider any horizontal plane ... at depth h below the top surface of the material. Let W_g be the weight of the grain ... W_c be the weight of the cone ...w this plane. The meridional tension ...s given by

$$\ldots \alpha \cdot 2\pi b = p_v \pi b^2 + W_g + W_c$$

$$N = \frac{p_v \pi b^2 + W_g + W_c}{2\pi b \sin\alpha} \quad \ldots(26.19)$$

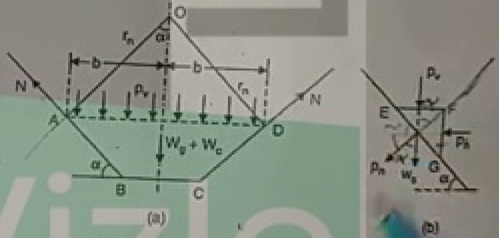


FIG. 26.7. CONICAL HOPPERS.

...p_n be the normal pressure. If w_s ...e self weight of the cone per ...area, we have, from Fig. 26.7(b)

$$p_n \cdot EG = p_v \cdot EF \cos\alpha + p_h \cdot FG \sin\alpha + w_s\, EG \cos\alpha$$

$$p_n = p_v \cos^2\alpha + p_h \sin^2\alpha + w_s \cos\alpha \quad \ldots(2\ldots$$

The ring tension T at any plane is given by

$$T = p_n \cdot r_n \quad \ldots(26.21\ (a))$$

r_n = radius of ...

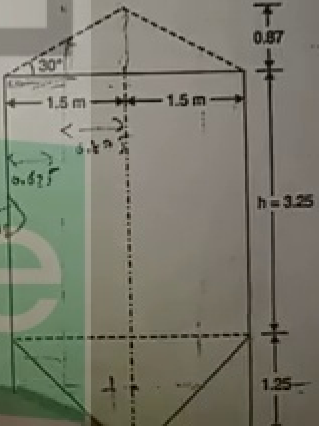
(ii) Vertical Reinforcement. Vertical reinforcement shall be at least 0.3% of the cross-sectional Half the number of bars on the inside and half on the outer side may be provided to take care of temperature and shrinkage stress. Where the base of the wall is fixed to the bottom, vertical reinforcement duly calculated shall be provided on the tension face.

A minimum cover of 5 cm shall be provided for the reinforcement.

Example 26.1. *Design a bunker to store 300 kN of coal, for the following data: Unit weight of coal = 8340 N/m³ ; Angle of repose = 30°. The stored coal is to be surcharged at its angle of repose. Take permissible stress in steel as 140 N/mm².*

Solution

1. *Capacity and dimensions* ... et us provide a square bunker of size 3 m × 3 m ... et the hopper portion have a height of 1.25 m w... a central hole of size 0.5 m × 0.5 m.



Height of surcharge = 1.5 ta... = 0.87 m.

Volume required = $\frac{300 \times 1000}{8340}$ ... m³

Volume provided by top sur...

$= \frac{1}{3}(3 \times 3)\,0.87 = 2.61$ m³

Volume provided by c...

$= \frac{1}{3}\left[3 \times 3 + 0.5 \times 0.5 + \right.$ ...

= 4.48 m. Alternat...

Height $h = \frac{28.88}{3 \times 3} = 3.21$ m. Let the height h be 3.25 m, so that its volume will be $3.25 \times 9 = 29.25 \text{ m}^3$, making a total capacity of $2.61 + 4.48 + 29.25 = 36.34 \text{ m}^3$ and storing $36.34 \times 8.34 = 303$ kN of coal.

2. *Design of side walls* : The side walls will be designed as continuous slab. Since the angle of surcharge is equal to the angle of repose ϕ, the horizontal pressure at any level is

$p_h = w\,h\cos^2\phi$ At 3.25 m depth.

$p_h = 8340 \times 3.25\,(\cos 30°)^2 = 20329 \text{ N/m}^2$

Using M 15 concrete mix, $m = 19$, $k = 0.404$, $j = 0.865$ and $R = 0.875$. Let the thickness of the wall be 180 mm. Effective span of slab $= l = 3 + 0.18 = 3.18$ m. $\therefore$ B.M. at the corners of the square frame $= \frac{p_h \cdot l^2}{12} = \frac{20329\,(3.18)^2}{12} = 17131$ N-m

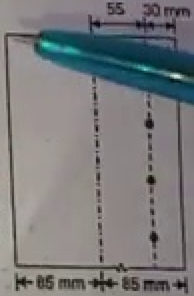


FIG. 26.12.

$K = \frac{m\,\sigma_{cbc}}{m\,\sigma_{cbc} + \sigma_{st}} = \frac{19 \times 5}{19 \times 5 + 140} = 0.404$, $j = 1 - \frac{k}{3} = 0.865$ $R = \frac{1}{2} \times 5 \times j \times k$

Direct tension in the wall $= \dfrac{20329 \times 3.18}{2} = 32323$ N.

Let the cover to the centre of steel be 30 mm, so that effective depth will be 170 – mm. The distance of centre of steel from the centre of the slab will be = 85 – 3 as marked in Fig. 26.12.

$\therefore$ Net B.M. $= 17131 - 32323 \times 0.055 = 15353$ N-m at the corners.

B.M. at the centre of span $= (p_h \cdot l^2)/24 = 8566$ N-m

$\therefore$ Net B.M. at the centre of span $= 8566 - 32323 \times 0.055 = 6788$ N

Effective depth $= \sqrt{\dfrac{15353 \times 1000}{1000 \times 0.874}} = 133$ mm.

... total depth of 170 mm, ... that effective depth $d = 170$ –

... be varied from ... mm at top to 170 mm

$\dfrac{32323}{140} = 1136$ mm^2

B.M = ...

Overall depth = 160 mm, effective depth ...

$$\text{Net B.M} = 10662 - \frac{36557}{1000}\left(\frac{160}{2} - 30\right)$$

$$\text{Effective } d = \sqrt{\frac{8834 \times 1000}{0.874 \times 1000}} = 100.5 \text{ mm}$$

$$A = \frac{8834 \times 1000}{140 \times 0.865 \times 130} + \frac{36557}{140} = 822 \text{ mm}^2$$;Spacin...

Hence provide 12 mm φ bars @ 130 mm ...

At the middle of the span, the B.M. will be half ... Net pull will be the same, i.e. 36557 N. Hen...

$$\text{Net B.M.} = 5331 - 36557 \times 0.05 = 3503$$

$$A = \frac{3503 \times 1000}{140 \times 0.865 \times 130} + \frac{36557}{140}$$

$= 484$ mm²

Spacing

$= 1000 \times 113 / 484 = 230$ mm.

These bars are to be provided at the outer face.

4. *Top and bottom ribs* : Provide a top rib of size 300 × 300 mm with a nominal reinforcement of 4-12 mm φ bars, and 6 mm φ stirrups @ 200 mm c/c. Similarly, provide a bottom rib (junc-...

A ...

Spacing of 12 mm φ b...

Spacing of 12 mm φ ...

3. *Design of hopper* ...

... as well as to bending mom... along the slope is due to ... the spacing

Let the thickness of ...

Total

... thickness of hopp...

$\frac{1}{3}$ of weight of hopper slab = ...

$\frac{1}{4}$ weight gate etc = 200 N (Say)

Total $W = 75750 + 13919 + 200 = 89869$ ...

Direct tension $= W \text{ cosec } \alpha = 89869 \text{ cosec } 45° = 127094$ ...

$A_t = 127094 / 140 = 908 \text{ mm}^2$

No. of 10 mm ϕ bars $= 908/78.5 \approx 12$. Provide half bars on each face.

Since the meridional tension decreases towards the opening, these bars may be curtailed to half at the opening. The slab is also subjected to B.M. due to bending of the slab spanning horizontally between the intersection of adjacent sloping faces. The horizontal span of the slab will increase from minimum at the opening to maximum at the junction, while the pressure will decrease from maximum at the opening to minimum at junction.

The section of the slab is normally designed at the centre of the hoppers, where depth upto coal surface $= 3.25 + \frac{1.25}{2} + \frac{0.87}{1.5} \times 0.625 = 4.24$ m.

Lateral pressure $p = wh \cos\phi$

Span of the strip $= \frac{3 + 0.5}{2} = 1.75$ ...

$p_v = w\,h + p \sin\phi = w\,h$ ... $h \sin\phi \cos\phi$

$p_h = p \cos\phi = w\,h$ ... ...00 $= 4500 \text{ N/m}^2$.

... Eq. 26.20.

Self weight of hopper slab lining ...

$\alpha = 45°$ ...

...ination ... $\sin^2\alpha +$ ... $\cos^2\phi \sin^2\alpha) +$ ...

$$B.M = \frac{41779\,(1.75)^2}{12} = 10662 \text{ N-m} \quad ; \quad \text{Pull} = \frac{p_n \cdot l}{2} = \frac{41779 \times (1.75)}{2} = 36557 \text{ N}$$

Overall depth = 160 mm, effective depth = 130 mm

$$\text{Net B.M.} = 10662 - \frac{36557}{1000}\left(\frac{160}{2} - 30\right) = 8834 \text{ N-m}$$

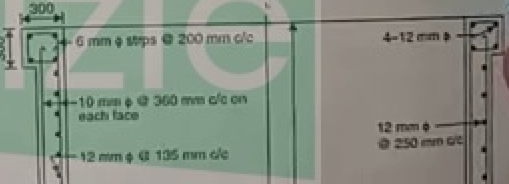
$$\text{Effective } d = \sqrt{\frac{8834 \times 1000}{0.874 \times 1000}} = 100.5 \text{ mm} \quad ; \quad \text{Actual } d \text{ provided} = 130 \text{ mm.}$$

$$A_{st} = \frac{8834 \times 1000}{140 \times 0.865 \times 130} + \frac{36557}{140} = 822 \text{ mm}^2 \quad ;\text{Spacing of 12 mm } \phi \text{ bars} = \frac{1000 \times 113}{822} = 137\text{mm}$$

Hence provide 12 mm φ bars @ 130 mm c/c at the inner face, at the corners. At the middle of the span, the B.M. will be half of the above value, *i.e.* $M = 5331$ ... Net pull will be the same, i.e. 36557 N. Hence

$$\text{Net B.M.} = 5331 - 36557 \times 0.05 = 3503 \text{ N-m. Hence,}$$

$$A_{st} = \frac{3503 \times 1000}{140 \times 0.865 \times 130} + \frac{36557}{140} = 484 \text{ mm}^2$$



Spacing

$= 1000 \times 113 / 484 = 230$ mm.

These bars are to be provided