DESIGN OF SILO

Generally, the Silos are circular in shape. These are designed similar to bunkers.

Design Procedure

Step 1: Calculation of horizontal pressure

By using the codal provisions, find the horizontal and vertical pressures at different depths at some intervals say 3 m, 4 m/5 m.

Step 2: Calculation of max. hoop tension

Hoop tension, $H_t = (p_h) \max \cdot \frac{D}{2}$.

Step 3: Design of wall plate

Calculate total vertical load, self weight, weight of lining, weight of top cover.

Calculate the vertical load.

Calculate thickness of plate from combined loading.

Step 4: Design of hopper

Calculate the total vertical load.

Calculate the direct tension.

Calculate the thickness $= \frac{\text{Direct tension}}{\sigma_{at} \times 1000 \text{ mm}}$

Step 5: Design of ring beam

Calculate the weight of stored material, self weight of silos lining cover, platform.

Calculate the reaction, SF, BM, torsion and compression.

Calculate σ_{ac}, $\sigma_{ac,\,cal}$, σ_{bc}, $\sigma_{bc,\,cal}$

Check for combined stresses.

Example

Design a circular steel silo of 10 m height and 4 m internal diameter to store cement of unit weight 15.50 kN/m^3 and $\phi = 25°$.

Solution

Step 1: Calculation of pressures

The mean size of particle is less than 0.06 mm.

For powdery material,

For filling, $\phi'f = 1.0\,\phi = 25°$

For emptying, $\phi'e = 1.0\,\phi = 25°$

Pressure ratio,

For filling, $\lambda_f = 0.5$

For emptying, $\lambda_e = 0.7$

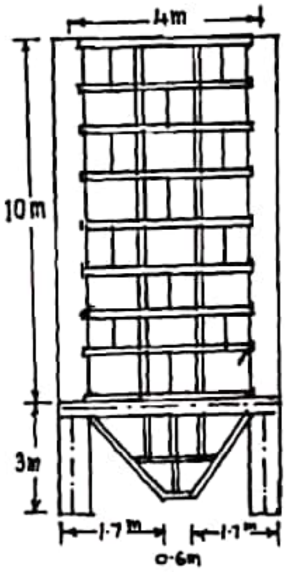
Angle of wall friction,

For filling, $\mu^1_f = \tan\phi^1_f$

$= 0.47$

For emptying, $\mu^1 e = 0.47$

$$R = \frac{d}{4} = 1.0 \text{ m}$$



$$Z_{oe} = \frac{R}{\mu^1_e \lambda_e} = \frac{1}{0.47 \times 0.70} = 3.064$$

$$Z_{of} = \frac{R}{\mu^1_f \lambda_f} = \frac{1}{0.47 \times 0.50} = 4.26$$

$$Z_{oe} < Z_{of}$$

$\therefore \quad \dfrac{h}{Z_{oe}}$ is more (emptying)

At 12 m

$$\frac{h}{Z_{oe}} = \frac{10}{3{,}064} = 3.26 \quad (1 - e^{-h/z_0}) = 0.96$$

Horizontal pressure, $p_h = \dfrac{\gamma R}{\mu^1_f} \times 0.96$

$$= \frac{1 \times 15.5 \times 0.96}{0.47} = 31.66 \text{ kN/m}^2$$

Vertical pressure, $p_v = \dfrac{\gamma R}{\mu^1_f \lambda_f} \times 0.96 = \dfrac{31.66}{0.50} = 63.32 \text{ kN/m}^2$

Step 2: Max. Hoop Tension

$$H_t = p_h \frac{D}{2} = 31.66 \times \frac{4}{2} = 61.32 \text{ kN/m}$$

Step 3: Design of Wall Plate

Total vertical load $= \dfrac{\pi}{4} \times 4^2 \times 10 \times 15.5 = 1948$ kN

Assume wt of silo + stiffeners and lining = 2 kN/m^2

Total wt. $= 2 \times \pi \times 4 \times 10 = 251$ kN

Weight of top cover = 4 kN/m^2

Total wt. $= \frac{\pi}{4} \times 4^2 \times 4 = 50$ kN

Total vertical load = 1948 + 251 + 50 = 2249 kN

Vertical load/mm length $= \frac{2249 \times 10^3}{\pi \times 4000} = 179$ N/mm

H_t = 61.32 kN/m = 61.32 N/mm

Let t be the thickness, 0.3 be the poisson ratio.

Max. compressive stress $= \frac{179}{t} + \frac{(0.3 \times 61.32)}{t} = 150$

$\therefore \quad t = 1.32$ mm

Adopt 8 mm thick plate.

Since the thickness provide is very lower than the required, nominal stiffeners are provided @ 1.50 m spacing.

Stiffeners ISA @ 6060, 6 mm

Step 4: Design of hopper

Vertical load $= \frac{\pi}{4} d^2 p_v$

$$= \frac{\pi}{4} \times 4^2 \times 63.32$$

$$= 795.70 \text{ kN}$$

Weight of material is hopper

$$= \frac{\pi}{12} \times 4^2 \times 3 \times 15.5$$

$$= 194.68 \text{ kN}$$

Self wt. = 60 kN (let)

Total load = 795.70 + 194.68 + 60 = 1050.38 kN

Length of hopper $= \sqrt{3^2 + 1.7^2} = 3.45$ m

Load/mm run $= \frac{1050.38 \times 10^3}{\pi \times 4000} = 84$ N/mm

Direct tension $= \frac{84 \times 3.45}{3} = 96.6$ N/mm

Assuming 8 mm thick plate tensile stress

$$= \frac{96.6}{8} = 12.1 \text{ N/mm}^2 < 150 \text{ N/mm}^2$$

$\therefore$ Safe.

Step 5: Design of Ring Beam

Weight of material stored

$$= \left(\frac{\pi}{4} \times 4^2 \times 10 = \frac{1}{3} \times \frac{\pi}{4} \times 4^2 \times 3\right) \times 15.5 = 2143 \text{ kN.}$$

Self wt. of silo lining, cover, platform

$$= 251 + 50 + 50 = 351 \text{ kN}$$

Total load = 2143 + 351

= 2494 kN

≃ 2500 kN (say)

Using 8 No. of supports.

$$\text{Reaction} \quad = \frac{2500}{8} = 312.5 \text{ kN}$$

$$\text{Shear force} = \frac{2500}{16} = 156.25 \text{ kN}$$

Bending moment at support

$= 0.00827\ WR$

$= 0.00827 \times 2500 \times 2$

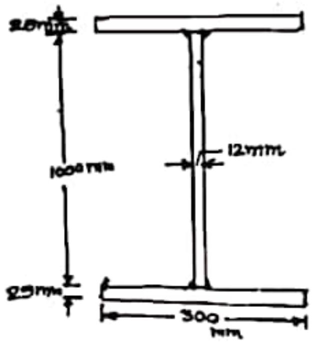
$= 41.35$ kN-m.

$$\text{Direct compression} = \frac{1}{2} \times \frac{2500}{1.7} \times 3 = 2206 \text{ kN}$$

Assume $\sigma_{ac} = 1200 \text{ N/mm}^2$

$$\text{Gross area required} = \frac{2206 \times 10^3}{120} = 18382.4 \text{ mm}^2$$

Adopting the sect shown in Figure 13.20.



$$A = 2\,(300 \times 25) + 1000 \times 12 = 27000 \text{ mm}^2$$

$$I_{XX} = \frac{300 \times 1050^3}{12} - \frac{288 \times 1000^3}{12}$$

$$= 49.4 \times 10^8 \text{ mm}^4$$

$$I_{YY} = \frac{2 \times 25 \times 300^3}{12} + \frac{1000 \times 12^3}{12}$$

$$= 1.13 \times 10^8 \text{ mm}^4$$

$$I_{min} = 1.13 \times 10^8 \text{ mm}^4$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{1.13 \times 10^8}{27000}} = 64.7\,\text{mm}$$

Length between two adjacent columns

$$l = \frac{\pi D}{8} = \frac{\pi \times 4}{8} \times 1000 = 1570.8\,\text{mm}$$

Slenderness ratio, $\lambda = \frac{l}{r_{min}} = \frac{1570.8}{64.7} = 24.2$

From Table 5.1, $\sigma_{ac} = 146\,\text{N/mm}^2$

$$\sigma_{ac,\,cal} = \frac{P}{A} = \frac{2206 \times 10^3}{27000} = 81.7\,\text{N/mm}^2$$

$$\sigma_{bc,\,cal} = \frac{M}{I} \cdot y$$

$$= \frac{41.35 \times 10^6}{49.40 \times 10^8} \times \left(\frac{1050}{2}\right)$$

$$= 4.4\,\text{N/mm}^2$$

$$\sigma_{bc} = 165\,\text{N/mm}^2$$

$$\frac{\sigma_{ac,\,cal}}{\sigma_{ac}} + \frac{\sigma_{bc,\,cal}}{\sigma_{bc}} = \frac{81.7}{146} + \frac{4.4}{165}$$

$$= 0.59 < 1.00$$

Hence safe.