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Plan, Analysis and Design of a Circular RCC Silo Structure by Considering Indian Seismic Zone

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***Abstract*—*Bunkers and Silos are the structures used for the storage of materials like grain, cereals, coal, cement etc. 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 named as 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 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 thin spherical or conical dome, or with a beam and slab type flat roof with suitable man-hole. The stored material exerts pressure on the side of a bin. This pressure varies during the filling and emptying processes, and also with the location of the discharging hole. The exact analysis of pressure is extremely difficult because of mainly variable factors. Therefore, approximate methods suggested by Janssen and Airy are commonly followed. This paper deals with the Planning, Analysis and Design of Circular RCC Silo as per Indian Standards taking into account the wind pressure which is to be constructed at Kumarajah Muthiah Nagar, Karur, TamilNadu, India.*

Keywords*— *Silo, Wall Section, Conical bottom, Hoop Tension. Cantilever Staircase, Pile Cap, Driven Pile.

I. INTRODUCTION

Silo is derived from the Greek word 'Siro' which means colliery for holding ounce, is a structure for storing loose materials. Initially it was started as a storing unit for agricultural grains and contents and was then expanded for the storage of many other materials such as cement, fly ash etc. Modification has been done to these silos to lodge the cement industry growth and some amendments have been made to the silo for improved storage of materials and for the lessening of silo failures.

There are three types of silos as of use today which are tower silos, bunker silos and bag silos. The silo industry has been growing at a rapid pace trying to better the design and looking for more innovations to improve the efficiency and the storage capacity of silos. A modernization which has evidenced having a high success rate is the multi-compartment silo. This silo provision stores the diverse varieties of materials which reduces the space usage and is more economical.

A new strategy is introduced latterly in the silo is the internal or central cone. Conservative silos have a cylindrical body and a hopper bottom, but an internal cone silo consists of cone inside the structure and does not hopper out.

Central cone type silo has many rewards such as the pressure lessening on the base of the silo when the material moves. Pressure Uniformity is detected in this silo type as the multi compartment walls are included which helps the hoop stress and longitudinal stress distribution on the walls of the silo structure. This feature enhances the safety of the structure and prevents high rates of failure. Care of the silo has also been enhanced by the provision of internal cone. There are also some silos that have a combination of both these features and have been proved to be very successful and show minimal failure rates. And the main aim of this project is to show the analysis and design of one such silo that is a multi-compartment hopper bottom silo and the benefits of its kind. Hopper bottom silos offer the advantages of complete silo cleanout and lower material handling costs.

The value of μ and μ' for various materials are given in table. The values of constants to be used in Janson's and Airy's formulae are given in table.

Material	Density kg/m^3	Coefficient of Friction		K= (1-sinϕ) /(1+sinϕ)
		Filling on filling μ=tanϕ	Filling on concrete μ'	
Cement	1440	0.316	0.554	0.5371
Coal	800	0.700	0.700	0.2709
Anthracite	835	0.510	0.510	0.3753
Coke	450	0.839	0.839	0.2174
Sand	1600	0.674	0.577	0.2830
Wheat	805	0.466	0.444	0.4062

II. STUDY AREA

A suitable site has been designated for the project. The site selected for the project is the branch of Chettinad cement plant at Kumarajah Muthiah Nagar, Karur, Tamil Nadu. Chettinad cement is operating its cement business spanning three generations and has been expanding and making itself versatile in the field of cement products.

Chettinad cements are judiciously balanced, highly precise mixtures of quality materials including combined cement and Portland cement manufactured under meticulous conditions assuring consistent performance and providing consistent quality. The highest temperature is got in early May to early June typically around 34 C. Average daily temperature during January is around 23 C though the temperature rarely falls below 17 C. The site detailing and selection has also been done after careful research of the site and the following details have been noted down such as the site falls under the seismic

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zone 3 as the site is located near Chennai that falls under this zone as per the revised codal version. Also the latitudinal and longitudinal gradients of the site are as follows, it is located at latitude of 10°56'14.46" and a longitude of 78°9'5.22".

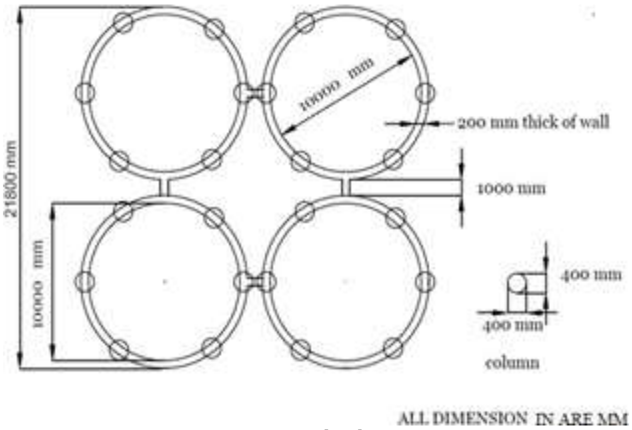

Fig. 1. Silo Plan.

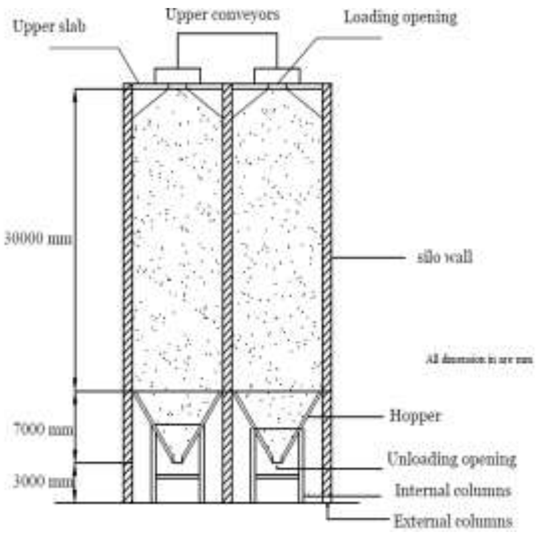

Fig. 2. Section View of Silo.

III. Design

A. *Given Details*

Concrete Mix = M20
Weight Density of Cement(w) = 15kN/m^3
Filling on Filling (μ) = 0.316
Filling on Concrete (μ$'$) = 0.554
Diameter of Circular Silo (d) = 10 m

B. *Shallow Portion*

Height at which rupture plane cuts vertical wall,
$h' = d \tan\theta$

$$h' = d \left[\mu + \sqrt{\frac{\mu\,(1+\mu^2)}{\mu+\mu'}} \right]$$

$$h' = 10 \left[0.316 + \sqrt{\frac{0.316(1+0.316^2)}{0.316+0.554}} \right]$$

h' = 9.5 m nearly

Intensity of horizontal pressure on the walls

$$P_h = w \times h \left[\frac{1}{\left\{\sqrt{\mu(\mu+\mu')}+\sqrt{1+\mu^2}\right\}^2} \right]$$

$$P_h = 15 \times h \left[\frac{1}{\left\{\sqrt{0.316(0.316+0.554)}+\sqrt{1+0.316^2}\right\}^2} \right]$$

$P_h = 6.062\ h$ kN/m^2 valid up to 9.5m

C. *Deep Portion*

$$P_h = \frac{wd}{\mu+\mu'} \left[1 - \frac{\sqrt{1+\mu^2}}{\sqrt{\frac{2h}{d}(\mu+\mu')+(1-\mu\mu')}} \right]$$

$$P_h = \frac{15\times10}{0.316+0.554} \left[1 - \frac{\sqrt{1+0.316^2}}{\sqrt{\frac{2h}{10}(0.316+0.554)+(1-0.316\times0.554)}} \right]$$

$$P_h = 173.6 \times \left[1 - \frac{1.0487}{\sqrt{0.174h+0.8249}} \right]$$, valid after 9.5m

TABLE I. Steel for Hoop Tension.

Depth (m)	P_h (kN)	Hoop Tension $P_h \times \frac{d}{2}$ (kN)	Hoop Steel $\frac{P_h \times 1.5 \times \frac{d}{2}}{0.87 \times 415}$ (mm^2)	Fe 415 Steel Spacing
2	12.124	60.620	251.85	10 mm Ø at 300 mm c/c
4	24.248	121.240	503.69	10 mm Ø at 150 mm c/c
6	36.372	181.860	755.54	10 mm Ø at 100 mm c/c
8	48.496	242.480	1007.40	16 mm Ø at 200 mm c/c
10	59.924	299.620	1244.78	16 mm Ø at 160 mm c/c
12	66.931	334.655	1390.34	16 mm Ø at 140 mm c/c
14	72.783	363.915	1511.90	16 mm Ø at 130 mm c/c
16	77.767	388.835	1615.43	16 mm Ø at 120 mm c/c
18	82.078	410.390	1704.98	16 mm Ø at 110 mm c/c
20	85.855	429.275	1783.44	16 mm Ø at 110 mm c/c
22	89.200	446.000	1852.93	16 mm Ø at 100 mm c/c
24	92.190	460.950	1915.04	16 mm Ø at 100 mm c/c
26	94.883	474.415	1970.98	16 mm Ø at 100 mm c/c
28	97.325	486.625	2020.70	16 mm Ø at 90 mm c/c
30	99.553	497.765	2067.99	16 mm Ø at 90 mm c/c

D. *Wall Section*

Hoop Tension at bottom of cylindrical portion = 497.765kN
For M20 mix, allowable tension in concrete is 2.8 N/mm^2
Allowable stress in concrete in bending compression for M20 concrete (σ_{cbc}) = 7 N/mm^2

Modular ratio (m) = $\frac{280}{3\sigma_{cbc}} = \frac{280}{3\times7}$ = 13.33

Assume wall thickness as 200 mm.
Actual Tensile Stress in concrete at the bottom of cylindrical portion where hoop tension is maximum

$= \frac{497765}{(200\times1000)+(13.33\times2068)}$ = 2.18 < 2.8 N/mm^2

Hence wall thickness of 200 mm is Safe and is provided throughout from top to bottom.

Vertical reinforcement is provided at 0.3% of wall section
Vertical steel = 0.3% of BD

$= \frac{0.3}{100} \times 1000 \times 200$ = 600 mm^2

Provide 16 mm diameter @ 300 mm c/c.

E. Load taken by wall

Provide roof on the top say 200 mm thickness allowing live load of 1500 N/m^2 load per 1 m perimeter of wall.

Roof Load = $\frac{(4800+1500)\times(\pi/4)\times d^2}{\pi d}$

$= \frac{6300\times(\pi/4)\times 10^2}{\pi\times 10}$ = 15749.8 N

Wall Load for 30 m height = 200$\times$ 1000 $\times$ 30 $\times$ 0.024
= 144000 N

Grain load carried by wall = μ' P

Where P = $\frac{wb}{2}$ (2h – b tanθ) $\left[\frac{(\tan\theta-\mu)}{(\mu+\mu')tan\theta+(1-\mu\mu')}\right]$

And tan$\theta = -\frac{(1-\mu\mu')}{(\mu+\mu')} + \sqrt{\frac{2h}{b}\times\frac{(1+\mu^2)}{(\mu+\mu')}+\frac{(1+\mu^2)(1-\mu\mu')}{(\mu+\mu')^2}}$

Substituting the values in the above equations, we get
tan θ = 1.969
P = 1969069.8 N
Grain load carried by the wall = 0.554 × 1969069.8
= 1090864.7 N

Total load carried by the wall
= 15749.8 + 144000 + 1090864.7 = 1250614.5 N

Compressive Load = $\frac{\text{Total Load}}{b\times d} = \frac{1250614.5}{1000\times 200}$ = 6.25 N/mm^2

Stress due to wind pressure:

Wind Pressure = 1500 N/mm^2
Shape factor = 0.7
Bending moment = Wind Pressure x Outer Diameter x Shape Factor x Height of Silo Wall x Inside Diameter
B.M = (1500 x 10.4 x 0.7 x 30 x 10) x 1000
= 327 x 10^7 Nmm

Moment of Inertia of Silo = $\frac{\pi}{64}\times[10.4^4 - 10^4]$
= 83.379 m^3

Section Modulus, Z = $\frac{I}{y} = \frac{83.379}{(\frac{10.4}{2})}$ = 16 m^3

Maximum Stress due to Wind Load = $\frac{327\times 10^7}{16\times 10^9}$ = 0.204 N/mm^2

Allowable Stress in Direct Compression for M20 Concrete = 5 N/mm^2

Total Compressive Stress = 6.25 + 0.204
= 6.454 > 5 N/mm^2

Hence it is not O.K

Hence M30 mix is adopted having allowable stress in direct compression = 8 N/mm^2

F. Conical bottom

Surcharge on conical portion,
= {(π/4)d^2 × 30 x 15000 – πd × 1090864.7}/{(π/4)d^2}
= 13654 N/m^2

Take height of the conical bottom, h=2.5 m and inside diameter of the opening = 0.25 m

Weight of grain in conical portion,
= 15000$\times \frac{1}{3}\times\pi$h x $(r_1^2 + r_2^2 + r_1 r_2)$
= 15000 $\times\frac{1}{3}\times\pi\times 2.75\times(5^2+0.25^2+(5\times 0.25))$
= 1136618.4 N

Weight of concrete in conical portion assuming thickness as 20 cm,

= 24000 x [{ $\frac{1}{3}\times\pi\times 2.75\times(5.2^2+0.45^2+(5.2\times 0.45))\} -$
$\{\frac{1}{3}\times\pi\times 2.75\times(5^2+0.25^2+(5\times 0.25))\}$]
= 226080 N

Weight of Gate = 2000 N

Total weight carried by conical portion will cause meridional tension in the cone.

If W is the load per 1m perimeter and θ is the inclination with the horizontal of the cone.

Now,
W = [13654 × (πd^2/4)/πd] + [(1136618.4 + 226080 + 2000)/πd]
W= 77574.69 N
θ = 45°
Meridional tension= T_m = 77574.69 × cosec 45
= 109707.2 N

Using Fe 415 steel and 12∅ bars,

Meridional reinforcement = $\frac{109707.2}{230}$ = 477 mm^2

Spacing = {(π × 12^2/4)/477}× 1000 = 237.10 mm

Provide 12 mm diameter @ 230 mm c/c converging to the lower end of the cone. Half the bars may be stopped half the way.

G. Hoop Tension

Hoop Tension depends on the diameter at various heights of the cone and intensity of pressure. As the diameter is greater at the top and intensity of pressure of pressure is greatest at the bottom, the hoop tension will be found at the middle of the cone and reinforcement is provided through out.

The section chosen is 1.375 m below the end of cylindrical portion.

Vertical pressure = 13654 + 15000 x 1.375
= 34279 N/m^2

Weight of concrete = 200 × $\sqrt{2}$ × 1000 × 0.024
= 6788.22 N

Grain Pressure = (13654 + 15000 x 1.375) × [(1-sinθ)/(1+sinθ)]
= 34279 × [(1-sin (tan^{-1} 0.316)) / (1+ sin (tan^{-1} 0.316))]
= 18405.24 N/m^2

Normal Pressure = [(34279 + 6788) cos θ/$\sqrt{2}$] + [18405.24 sin θ/$\sqrt{2}$]
= 31610.65 N/m^2

The diameter of cone at midlevel of the conical portion
= 0.5 + (10 – 0.5)/2 = 5.25 m

Radius at this section = 5.25/2 =2.625 m
r_n = 2.625 × cosec 45° = 3.712 m
Now Hoop Tension, T = 31610.65 × 3.712 = 117338.7 N
Hoop Reinforcement = 117338.7/230
= 510.17 mm^2

Hence provide 10 mm ∅ bar rings @ 140 c/c throughout the height of the cone.

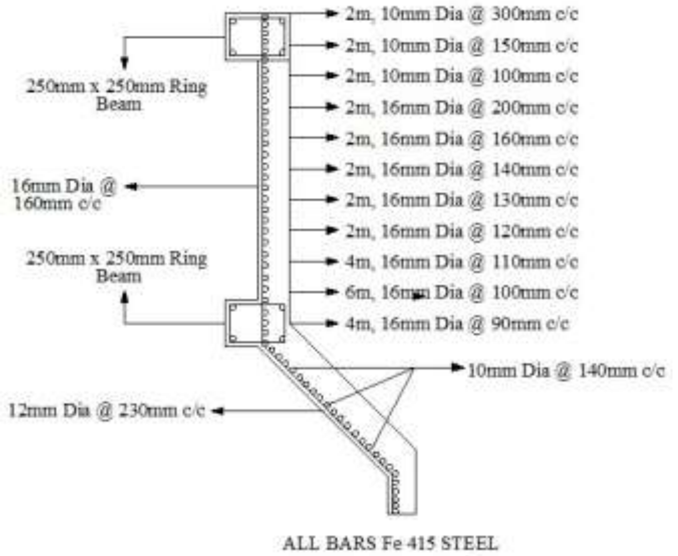

Fig. 3. Silo Reinforcement Details.

H. Helically Reinforced Columns

Assumed Data:

Both ends are pinned

Diameter of column = 400 mm

f_{ck} = 30 N/mm^2

f_y = 415 N/mm^2

Total load on Silo = 1250.6 kN

Number of Columns = 6 no's

Load on each Column = 1250.6/6 = 208.4 kN

Factored Load(P_u) = 1.5 × 208.4 = 312.7 kN

Size of Column (D) = 400mm

Cover = 40mm

D_{core} = 320 mm

$e_{minimum}$ = L0 /500 +D/30

= 4000/500 +400/30

= 21.33mm > {(D/20) =(400/20) = 20mm}

As $e_{minimum}$ > D/20, theoretically short column formula having centrally loaded column is not applicable. However the column is designed as centrally loaded as the moment to be considered is small.

Slenderness of column:

L_e/D = 4000/400 = 10.0 < 12

Hence the column is designed as a Centrally Loaded Short Column.

Area of longitudinal steel:

$P_u = 1.05[0.45\ f_{ck}\ A_c + 0.67\ fy\ A_{st}]$

$A_c = \pi\ d^2/4 = \pi \times 400^2/4 = 125600\text{mm}^2$

$312.7\text{x}10^3 = [0.45 \times 30\ (125600\text{-}A_{st}) + 0.67\text{x}415\text{x}A_{st}]$

$= 1695600 + A_{st}\ (278\text{-}13.5)$

Concrete itself can carry more than the required load hence provided minimum steel.

A_{st} (minimum) = 0.8% (of area required to carry P_u) as to resist given by,

$$A_{st} = \frac{P}{1.05\text{x}0.45\text{x}fck} = \frac{313\times10^3}{1.05\times0.45\times30} = 22081\text{mm}^2$$

$$A_{st}\ (\text{minimum}) = \frac{0.8}{100}\times 22081 = 176.65\ \text{mm}^2$$

Provide 6 no's of 12mm bar given area 678mm2 as minimum number of bars allowed is 6 numbers.

Design of spirals:

Choose 6mm

A = πd^2/4 = πx62/4 = 28.27mm2

S = Pitch

$$S = \frac{11.1\times A\times D\times f_y}{(D^2-D_c^2)f_{ck}}$$

$$= \frac{11.1\times28.27\times400\times415}{(400^2-320^2)\times30}$$

= 30.14mm

Spacing not more than 75mm

Spacing not more than = 320/6 = 53.33mm

Spacing not less than 25mm

Spacing not less than (6 × 3) = 18mm

Hence choose spacing as 30mm.

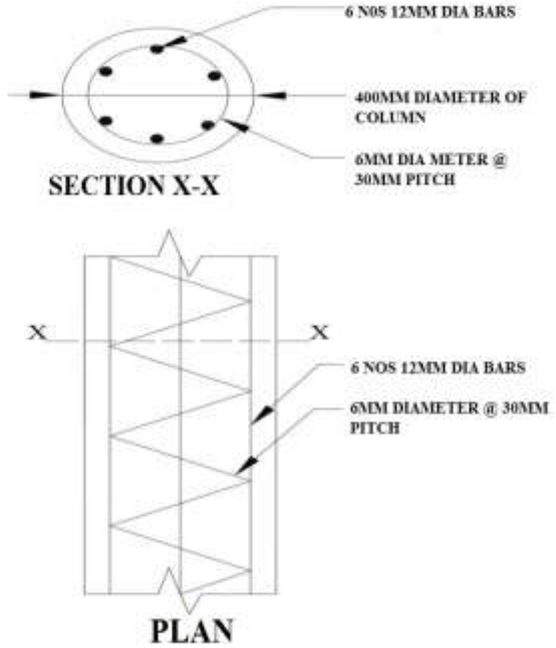

Fig. 4. Column Reinforcement Details

I. Cantilever Staircase

Data for assumed:

Waist (W) = 75mm

Rise (R) = 175mm

Tread (T) = 250mm

Going (G) = 225mm

Cantilever for a clear width =1.5m

Assumed live load = 3.0 kN/m^2

Use M30 grade and Fe 415 steel

Each tread is designed as a cantilever beam

$B = \sqrt{G^2 + R^2}$

$B = \sqrt{225^2 + 175^2}$ = 285mm

Load on each step for one meter transversely:

Dead load = weight of (waist + steps)

= [BW +TR/2] × 25

= [0.285X0.075+(0.250X0.175/2)] × 25

= 1.07KN/m
Live load on 0.225m width along the step transversely
= 0.225x3 = 0.68kN/m
Design loads:
W = 1.5(DL+LL)
= 1.5(1.07+0.68) = 2.63KN/m
Bending moment as cantilever:
M = $wl^2/2 = 2.63x1.5^2/2$ = 2.95KN/m
Moment capacity from effective depth:
Effective depth = mean depth - cover - diameter/2
Mean depth = R/2+W (B/G)
= 175/2+75 (285/225) = 182mm
d = 182−25−6 = 151mm
Mu = $kbd^2 = 4.14\ bd^2$
= $4.14 \times 225 \times (151)^2$
= 21.24 kN/m > 2.95 kN/m
Area of main steel = M/bd^2
= $2.95 \times 10^6/225 \times (151)^2$
= 0.575
From SP16, Table 4; for M/bd^2 = 0.575
Percentage of steel = 0.163%
A_{st} = 0.163x225x151/100 = 55.37mm^2
Provide 10mm rod on top of each steps 79mm^2.
Check for deflection:
L/d ratio = 1500/151 = 9.9
Percentage of steel = 0.357
Modification factor F_1 = 1.4
Permissible L/d = basic x 1.4 = 7x1.4 = 9.8
Check for shear:
V = wl = 2.63x1.5 = 3.95KN
u = V/(bd) = $3.95 \times 10^3/(225 \times 151)$ = 0.12N/mm^2
Minimum τ_c for M30concrete = 0.37N/mm^2
Hence section is safe without shear steel.

J. Pile Cap

Factored load on a silo column = 1250.6 KN
Column diameter = 400 mm
Pile diameter (h_p) =450 mm
Spacing of piles (L) = 1350 mm c/c
f_{ck}= 30N/mm^2
f_y =415N/mm^2
Arrangement of pile cap:Keep 4 piles in square section under the pile cap with an extension of pile cap equal to 150mm on all side from outside of pile.
Size of pile cap = 1350 + 450 + 300 = 2100 mm
Depth of pile cap:
Total thickness of pile cap= $2h_p$+100 = 2x450+100 = 1000mm
Adopt effective depth (d) = $\frac{1}{2} \times$ spacing of pile
= 1350/2
= 675mm
Adopt Cover 75mm
Assuming 20mm rods
Tension steel:
$T = \frac{P}{24Ld}(3L^2 - a^2)$
$= \frac{1250.6}{24 \times 1350 \times 675} \times 3 \times (1350^2 - 400^2)$
= 285.2kN

$A_S = \frac{T}{0.87\ f_y} = (285.2 \times 10^3)/(0.87 \times 415) = 790$ mm^2
But Minimum Tension Reinforcement
$A_S = \frac{0.85\ bd}{f_y} = \frac{0.85 \times 2100 \times 675}{415} = 2903$ mm^2
Provide 16 no's of 16 mm Ø giving 3216 mm^2
Check for shear (f_{ck}=30):
a_v = 675-200-150+(300/5) = 385 mm
For M30 concrete , τ_c= 0.37 N/mm^2
$\tau'_c = \tau_c\ (2d/a_v)$
= 0.37(2x675/385)
=1.297 N/mm^2
Shear (τ_v) = V/ (bd)
= (1250.6×1000)/(2100×675)
= 0.88 N/mm^2
$\tau_v < \tau'_c$
0.88 N/mm^2 < 1.297 N/mm^2
Hence Safe.

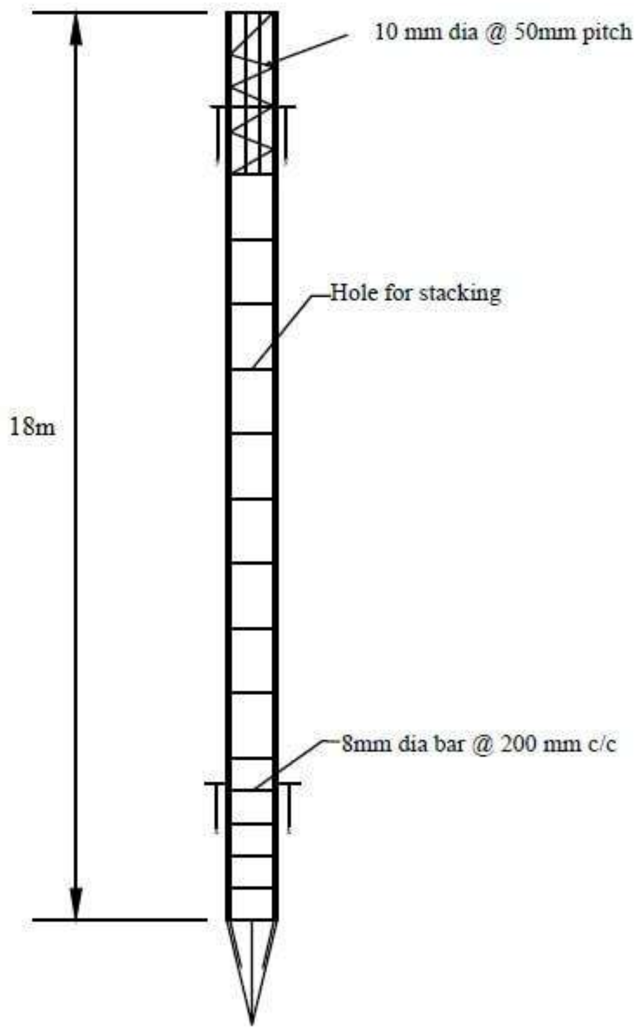

Fig. 5. Pile Reinforcement

K. Driven Pile Foundation:

Assume weight of the foundation =15% extra of the weight of the column

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Proposed transfer of load (Q_{ug}) = 1250.6 + 0.15 × 1250.6
= 1438.2 kN

Assume the clay unconfined compressive strength (q_u) = 65kpa

Diameter of the pile (D) =0.45 m

Angle of wall friction between pile and soil (α) =0.7

Average cohesion throughout of the length of pile:

$C = q_u/2 = 65/2 = 32.5 kN/m^2$

Group action:

$Q_f = n [\alpha.C.\pi.D.L] = 4 [0.7x32.5 \text{ x } \pi \text{ x } 0.45 \text{ x } L]$
$= 128.6 \times L$

$Q_{ug} = Q_f$ / F.O.S

$1438.2 = \frac{128.6\, L}{1.5}$

L= 16.77 m ~ 18 m

IV. Conclusion

Large amount of essential materials like Rice, Wheat, Fly Ash and Cement gets wasted due to storage of materials in warehouse and storage bags kept in open areas. To overcome this, massive storage structures like Silo is adopted. In this project, we have designed walls, conical hopper bottom, columns, cantilever staircase, pile cap and driven pile. Thermoplastic is added to the plastering material during plastering of the inner surface of the silo to avoid moisture absorption from outside.

References

[1] IS 456 -2002: “Plain and Reinforced Concrete –Code of Practice”.
[2] IS 4995 (Part I & II) – 1974: “Criteria for Design of Reinforced Concrete Bins for The Storage of Granular and Powdery Materials”.
[3] Falgunibasu, “Design of storage for storing granular materials” Indian concrete journal, Vol.75 (2002/2/19).
[4] B. C. Roy, “Wall pressure for pipe flow reign inside discharge bins”, the bridge and structural engineering 1997 pp No. 1-120 (1997)
[5] V.N. Vazirani and M.M. Ratwani, “Design of Reinforced Concrete Structures”, Khanna Publishers.
[6] P.C.Varghese, “Limit State Design of Reinforced Concrete”,Prentice Hall of India Private Limited, New Delhi.
[7] B.C.Punmia, Ashok Kumar Jain, Arun K.Jain, “R.C.C Designs”, Laxmi Publications (P) Limited.
[8] N.Krishna Raju, Ädvanced Reinforced Concrete Design”, CBS Publishers & Distributors Pvt.Ltd.

R. Gunaseelan and M. Rajiv, “Plan Analysis and Design of a Circular RCC Silo Structure by considering Indian Seismic Zone,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 4, pp. 150-155, 2019.