Analysis and design of reinforced concrete silo by conventional method

Dumma Umesh Kumar[1], and *V.Mallikarjuna* Reddy[1]

[1]Department of Civil Engineering, GRIET, Hyderabad, Telangana, India

Abstract. Any industrial or organised storage facility needs bulk material storage structures, also referred to as bins, bunkers, silos, or tanks. The ratio of their various dimensions serves as the main defining characteristic between bunkers and silos. Silos are structures that are used for storing different types of granular material. Silos are architectural constructions made especially for storing different kinds of granular materials, such grains and cement. Silos are distinguished by their disproportionately tall lateral dimensions. For instance, massive silos are frequently used to store cement in cement mills and significant construction projects. The project's main goal is to analyse and design a silo made of reinforced cement concrete. The theory adopted for analysis of silo is Janssen's theory. The silo is designed for storing the cement clinkers with a capacity of 5000 tonnes. The normal pressure calculation during emptying and filling, and maximum pressure calculation has performed. The hoop stresses and Temperature stresses are calculated and hoop tension is calculated for different heights. The assessment of the loads on silo was performed as per IS: 4995 (Part I) - 1974, and for design criteria IS: 4995 (Part II) – 1974 is used.

1 Introduction

A silo is a type of architectural building used largely for the storage of huge quantities of bulk goods like grain, coal, fly ash, cement and food items. Reinforced cement concrete silos have largely supplanted the more widely used steel silos in recent years because of their superior structural qualities and ease of maintenance. Concrete is frequently stored in one or more silos by contemporary cement companies. Additionally, silos can be built more effectively thanks to the slip form method, which involves casting tall cylindrical buildings out of reinforced concrete.
The vertical walls of silo constructions are substantially taller than their lateral dimensions, making the total structure relatively tall. As a result of its shape, the silos opposite sides will be intersected by the stored material's plane of rupture before it reaches the top horizontal surface. Additionally, a sizeable portion of the load is supported by friction between the material being stored and the silo's floor because of the high height to lateral dimension ratio. A building must fulfil specific requirements in order to be classified as a silo,

$$h > b \tan((90+\Phi)/2) \qquad (1)$$

Where,
b = Breadth
h = Height of the structure

Φ = Angle of repose.
Special silos are those which are different in respect to the structural configuration like Multi-Compartment Silos, Ring Silos and the combination of two, i.e., which contains compartments in the ring.

2 Review of Literature

Bogrem Sasidhar and C.Sashidhar (2021) The goal is to examine a silo with the Corresponding Lateral Force examine and assess how well it performs throughout all four seismic areas. Comparing several concrete silo models under earthquake conditions is involved in this. Elements such nodal displacement, stress, and vertical or horizontal pressure on walls are all examined. The potential and applicability of these models in precisely comprehending the actions of such structures can be evaluated through the acquired similar outcomes. The maximum lateral displacements for each model at different levels were determined in the present study by Anurag Ravindra Warade and Dr. Tushar G. Shende (2019) for the critical load case/combination. Zone V had node changes that were larger than those in the other seismic zones, measuring 9.357 mm at a height of 36 Mt in the silo. Zones II, III, IV, and V of the silo's maximum absolute stresses were measured to be 1.28 N/mm^2, 1.37 N/mm^2, 1.48 N/mm^2, and 1.67 N/mm^2, respectively. Zones II, III, IV, and V of the silo were found to have maximum shear stresses of 0.649 N/mm^2, 0.693 N/mm^2, 0.753 N/mm^2, and 0.841 N/mm^2, respectively. The goal of this study was to figure out how silos behaved in the presence of earthquake and wind loads. For study, a silo model was chosen, and its static as well as dynamic design were both assessed. The results of manual static examination were compared to those of the programme's static analysis in order to validate the software data. The software's correctness for analysis and design was demonstrated by the fact that the findings were the same. Based on pertinent IS regulations including IS 1893, IS 456, and IS 875, the combination of earthquake and wind loads was calculated. According to the investigation, compared to static loads, earthquake and wind loads put more stress on the silo. The silo needs to be built to handle additional earthquake and wind forces in order to endure the added strains during earthquakes and strong winds. As shown in the accompanying photographs, the failure of numerous silos is linked to their lack of seismic design. An evaluation of the performance of a concrete cylindrical silo under earthquake and wind load circumstances was done in a study by Akshitha I. Mesharam and Sanyaj K. Bhadke in 2018. Static and dynamic design evaluations of a typical silo model were performed, and human analysis was used to verify the software-generated data used for static analysis. The consistency of the outcomes from the two approaches shows the software's accuracy in carrying out analysis and design activities. The combination of earthquake and wind loads to be employed in the study was determined by consulting the pertinent IS regulations, such as IS 1893, IS 456, and IS 875. According to the investigation, the silo was subjected to greater strains during conditions of earthquake and wind load than under static loads. In order to counterbalance these stresses, silos must be built to endure additional earthquake and wind forces. For a silo with a 3500 MT capacity, Ankith Saxena and Anjali Malik produced a design calculation report. The silo was built from reinforced concrete and has a level platform for extraction and discharge needs. Clinker was used to fill the silo, which had an internal diameter of 14 metres and an overall height of 35.40 metres. The silo model was created using the Staad software, taking into consideration all the necessary loads, including material loads, dead loads, live loads, wind loads, seismic loads, symmetrically filling loads, symmetrically filling loads with patches, and symmetrically discharging loads. Based on the Staad results, base pressure calculations have been made. For every component at the top and bottom of the foundation, the reinforcement for moments (MX and MY) has been calculated, and detailing has been finished as a result.

3 Materials used in Design

1. M30 is the concrete grade for slabs and vertical walls.
2. HYSD bars with a minimum yield strength of 500N/mm^2 are utilised as reinforcement.
3. Annular Raft has been designed for Safe Bearing Capacity of 800KN/m^2

4 Method of Construction

Silo vertical walls will be built using slip forms, but the Annular raft and Deck slab will be built using traditional methods.

5 Input Data Considered for Design

1. Material to be stored in silo	= Clinker
2. Weight of Material Stored in Storage Silo	=5000 Ton
3. Thickness of RCC Wall of Storage Silo	=300 mm
4. Thickness of roof slab including steel support	= 1.5m
5. Thickness of Top Slab of Silo	= 200 mm
6. Thickness deck slab	=1200 mm
7. Elevation of bottom of deck slab above GL	= 10 m
8. Elevation of Top of roof Slab above GL	=36.30 m
9. Max. Level of Filling below Silo Top	=1.50 m
10. Effective Height of Material Stored	=19.71m
11. Internal Diameter of Storage silo D	=14m
12. Angle of internal friction of stored material (Ø)	= 36˚
13. Slenderness Ratio (hc / dc)	=1.40
14. Temperature of Hot Material inside Ti	=100^{o}C
15. Temperature of lowest anticipated outside sol-air T_0	=15.4^o C
16. Design density of stored material	=1.65 T/m^3
17. Seismic Zone II	=0.1
18. Design Wind speed	=44m/sec
19. Grade of Conc. for wall (Characteristic Strength)	=30N/mm^2
20. Thickness of RCC Wall below deck slab bottom level	=700 mm
21. Yield Stress of Reinforcement	=500 N/mm^2
22. Grade of Conc. for foundation	=30N/mm^2
23. Depth of Foundation below ground level (GL)	=5 m
24. Bottom of Foundation from GL	=6.0 m
25. Outer Diameter of Foundation	=16.6 m

6 Loads considered and Calculations.

The loads that are commonly considered while designing conventional structures in accordance with applicable codes include Dead load, Live load, Wind load, Seismic load, and Temperature load. But in addition to the loads that act on regular structures, it is also necessary to consider the additional load brought on by the stored materials when designing silos.

Dead load + Live Load Calculations

Total load for Silo Full Condition, i.e. silo contain the material for its full capacity =81268.04 KN
Total load for Silo Empty Condition, i.e. silo does not contain any material =31205.08 KN

Temperature Load (IS 4995-part-2)

Moment due to Temperature, $M\Delta T$ $=\varepsilon t * \Delta T * EC * I/t$
Material contact portion, $M\Delta T$ =88.31 kN-m/m
Above material, $M\Delta T$ =82.3 kN-m/m

Wind Load

Wind load per unit height of structure, $Fz = P_Z C_D d_Z$ = 614.78KN

Seismic loads

Base Shear VB = 5932.57 kN. (When Silo is full)
Base Shear VB = 2277.98 kN. (When Silo is Empty)

Estimation of Material Pressures during filling and emptying

Angle of wall friction during filling (δ_f) = 27.00
Angle of wall friction during emptying (δ_e) = 21.60
Pressure ratio during filling (λ_f) = 0.5
Pressure ratio during emptying (λ_e) = 1.0
Coefficient of Wall friction during filling ($\mu_f = \tan\delta_f$) = 0.510
Coefficient of Wall friction during emptying ($\mu_e = \tan\delta_e$) = 0.395
Horizontal pressure during filling $P_{hf} = (WR)/(\mu_f)$ =113.34 kN/m^2
Horizontal pressure during filling $P_{hf} = (WR)/(\mu_e)$ =145.86 kN/m^2
Frictional pressure during filling (WR) =57.75 kN/m^2
Frictional pressure during emptying (WR) = 57.75 kN/m2
Vertical pressure during filling on deck slab $P_{vf} = (WR)/(\mu f\ \lambda f)$ =226.68 kN/m2
Vertical pressure during filling on deck slab $P_{ve} = (WR)/(\mu e\ \lambda e)$ =145.86 kN/m2
Maximum horizontal pressure during filling (phf) $*(1 - e^{(-z/zof)})$ =86.34 kN/m2
Maximum horizontal pressure during emptying =130.17 kN/m2
Maximum frictional pressure during filling =43.99 kN/m2
Maximum frictional pressure during emptying =51.54 kN/m2
Maximum vertical pressure during filling on deck slab (P_{vf}) =325.21 kN/m2
Hoop Tension (T) =P*(D/2)
(Maximum vertical pressure during filling on deck slab shall be taken as twice of the filling pressure, however the load need not be assumed to be greater than WZ)

Table 1: Hoop Tension in Top Wall

S. No	Levels(from Top of Wall) in 'm'	Hoop Tension
1.	0-5	441.07 kN
2.	5-10	691.60 kN
3.	10-15	833.91 kN
4.	15-19.71	911.19 kN

Table 2: Variation of pressure along the depth during filling

Depth from silo top (Z) in m	$(1 - e^{\frac{-z}{z_{of}}})$	Horizontal pressure (ph_f) in kN/m²	Vertical pressure (ph_v) in kN/m²	Wall frictional pressure (pw_f) in kN/m²
0	0.00	0.00	0.00	0.00
1	0.07	7.96	15.91	4.05
2	0.14	15.36	30.71	7.82
3	0.20	22.23	44.47	11.33
4	0.25	28.63	57.26	14.59
5	0.31	34.58	69.15	17.62
6	0.35	40.11	80.21	20.44
7	0.40	45.25	90.50	23.05
8	0.44	50.03	100.06	25.49
9	0.48	54.47	108.95	27.76
10	0.52	58.61	117.21	29.86
11	0.55	62.45	124.90	31.82
12	0.58	66.02	132.04	33.64
13	0.61	69.34	138.69	35.33
14	0.64	72.43	144.86	36.91
15	0.66	75.30	150.61	38.37
16	0.69	77.97	155.95	39.73
17	0.71	80.46	160.91	40.99
18	0.73	82.77	165.53	42.17
19	0.75	84.91	169.82	43.26
19.71	0.76	86.34	172.69	43.99

Table 3: Variation of pressure along the depth during Emptying

Depth from silo top (Z) in m	$(1 - e^{\frac{-z}{z_{oe}}})$	**Horizontal pressure (ph_f) in kN/m²**	**Wall frictional pressure (pw_f) in kN/m²**
0	0.00	0.00	0.00
1	0.11	15.60	6.18
2	0.20	29.53	11.69
3	0.29	41.98	16.62
4	0.36	53.09	21.02
5	0.43	63.01	24.95
6	0.49	71.87	28.46
7	0.55	79.78	31.59
8	0.60	86.85	34.39
9	0.64	93.16	36.89
10	0.68	98.80	39.12
11	0.71	103.83	41.11
12	0.74	108.3	42.89
13	0.77	112.34	44.48
14	0.79	115.93	45.90
15	0.82	119.13	47.17
16	0.84	121.99	48.30
17	0.85	124.54	49.31
18	0.87	126.82	50.21
19	0.88	128.86	51.02
19.71	0.89	130.17	51.54

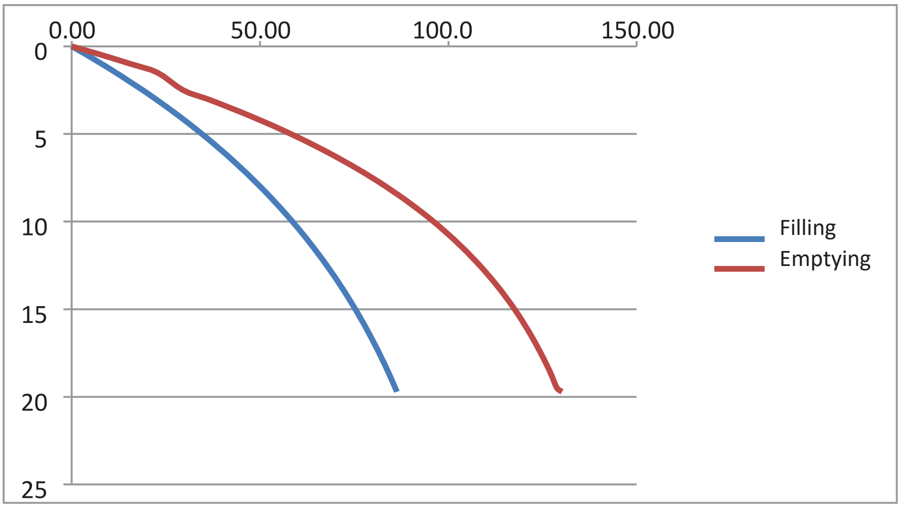

Fig.1: Variation of pressure along the depth during filling and emptying

Table 4: Distribution of Design force on the structure

S. No	Description of Load	Dead Load (kN)	Live Load (kN)	Height of storey (h_i) in m	$W_ih_i^2$	$Q_i = V_B(W_iH_i^2/\sum W_iH_i^2)$	Q_ih_i (kN-m)
1.	Roof Slab	837.07	837.07	41.3	2855563	504	20833
2.	Material (80%)	-------	40050	24.85	24732004	4369	108572
3.	Top Wall	8457	---------	24.85	5222437	922	22926
4.	Bottom Wall	7642	---------	10	764192	135	1350
5.	Foundation	8042.47	---------	1	8042	1.42	1.42
				$\sum W_iH_i^2$=33582240		**$\sum M_i$ =153683**	

7 Results

Design of Roof Slab

Slab is divided into number of small slabs
Designed as one way slab
Depth of roof slab =200mm
Main Reinforcement provided is =D10 at 150mm spacing
Distribution Reinforcement provide is =D10 at 250mm spacing
Designed and provided steel beam is =ISMB200

Designed and provided plate girder –Flange 360 x 30 mm
- Web 750 x 12 mm
-No stiffeners are required
-5mm intermitted weld of length 40mm and a gap of 100mm

Design of Top RCC wall

Table 5: Hoop Reinforcement Details in Top Wall

S. No	Levels(from Bottom of Top Wall) in 'm'	Reinforcement
1.	0-4.71	D20 at 130 mm c/c both faces.
2.	4.71-9.71	D20 at 180 mm c/c both faces.
3.	9.71-14.71	D20 at 200 mm c/c both faces.
4.	14.71-19.71	D20 at 200 mm c/c both faces.
5.	19.71-25.2	D20 at 200 mm c/c both faces.

Vertical Reinforcement

Minimum Vertical reinforcement = 0.2% of c/s.
∴ Provide D12 at 300 mm Spacing on each face.

Design of Bottom wall

Provided the wall thickness =700mm
Minimum circumferential reinforcement = 0.25% of c/s.
Provided -D20 at 200 mm Spacing
Minimum Vertical reinforcement = 0.2% of c/s
Provided -D20 at 250 mm Spacing on each face

Design of opening

Provided Size of opening – 4000 X 6000 mm
Width of column around opening = 2100mm
Vertical load on column is less than Capacity of column.
Hence Provide Minimum Vertical Reinforcement = 0.8%
= 11760 mm^2.

Design of Deep Beam

Effective span =4.6m
Depth of beam =4m
Provided -D32 at 120 mm Spacing

Design of deck slab

Maximum Vertical Pressure = 325.21 kN/m^2
Depth = 1200mm
For radial steel provided -D28 at 100 mm Spacing in 2 layers.

For tangential steel Provided - D28 at 130 mm Spacing in 2 layers.
Providing D-16 Shear leg (Z-bar) Stirrups @ 220 mm c/c.

Foundation

Annular raft footing analysis and design[16]
External diameter =16.6m
Internal diameter =9.2m

Table 6: Coefficients of Annular Raft Foundation

Coefficients	Axial load	Moment
Y_1	-0.3614	0.9797
Y_2	-0.8491	-2.1434
Y_3	-0.8973	0.1630
Y_4	-2.4573	1.1321
Y_5	-4.9376	2.9089
Y_6	3.7097	-6.0183
Y_7	-4.7836	2.0680
Y_8	-8	12

Table 7: Axial Load and Moment on Foundation

	Due to Axial load (kN-m)	Due to Moment (kN-m)
M_{ri}	-447.47	-244.40
M_{ti}	1020.10	46.11
Q_{ri}	-950.90	-404.90

By designing provided Radially steel = D25 @150mm c/c
Provided Tangentially steel =D25 @ 125 c/c

Top Reinforcement for Footing

But Minimum Area of steel = 0.15 % of bD
= 1800 mm^2.
Provided =D20 at 300mm c/c in both directions

8 Reinforcement Detailing

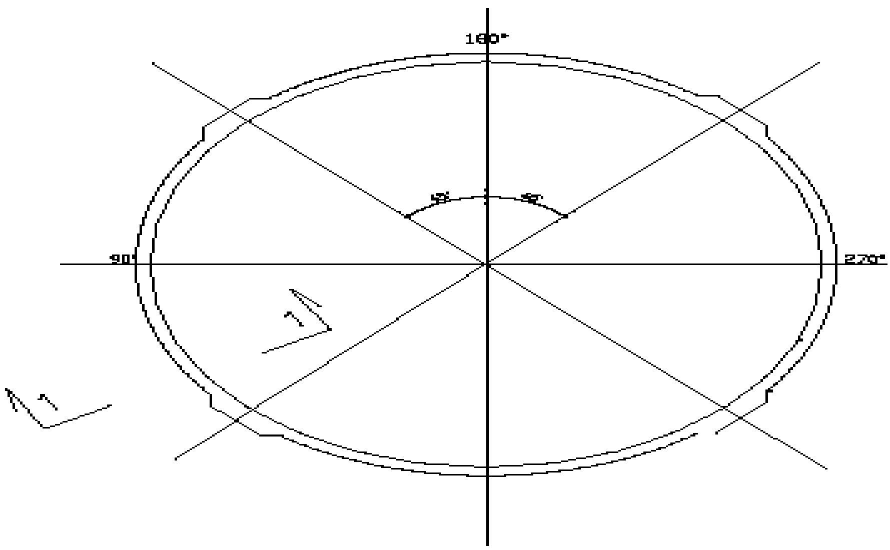

Fig.2: Key Plan of Silo Structure

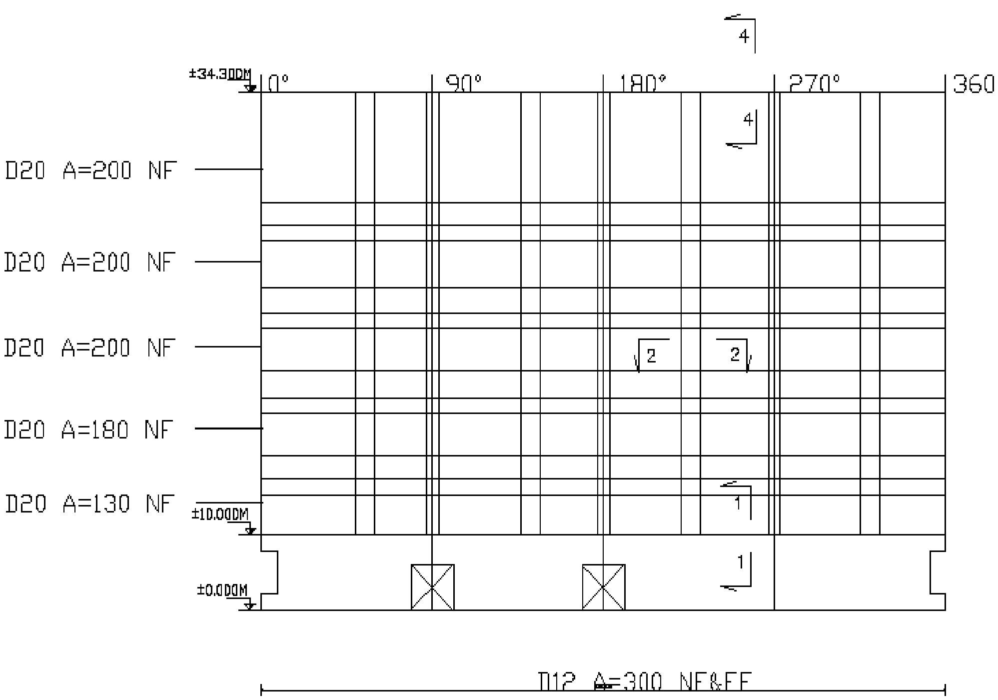

Fig.3: Reinforcement details for Top wall

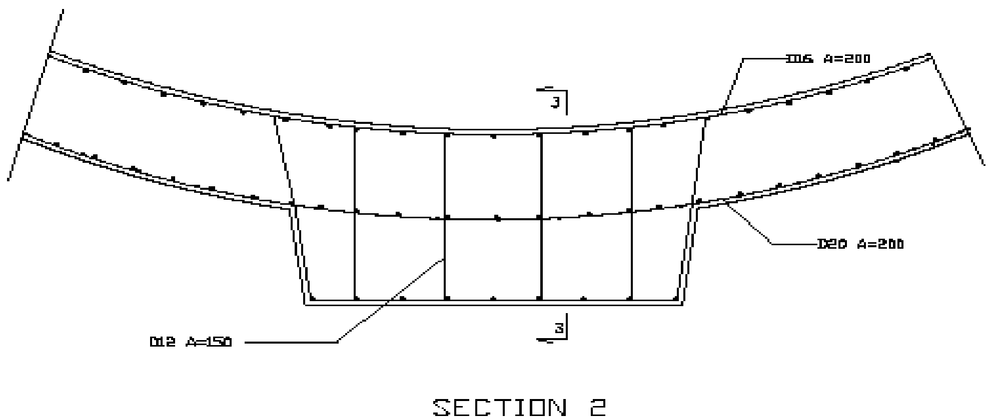

Fig.4: Reinforcement details for Top wall and Pilasters

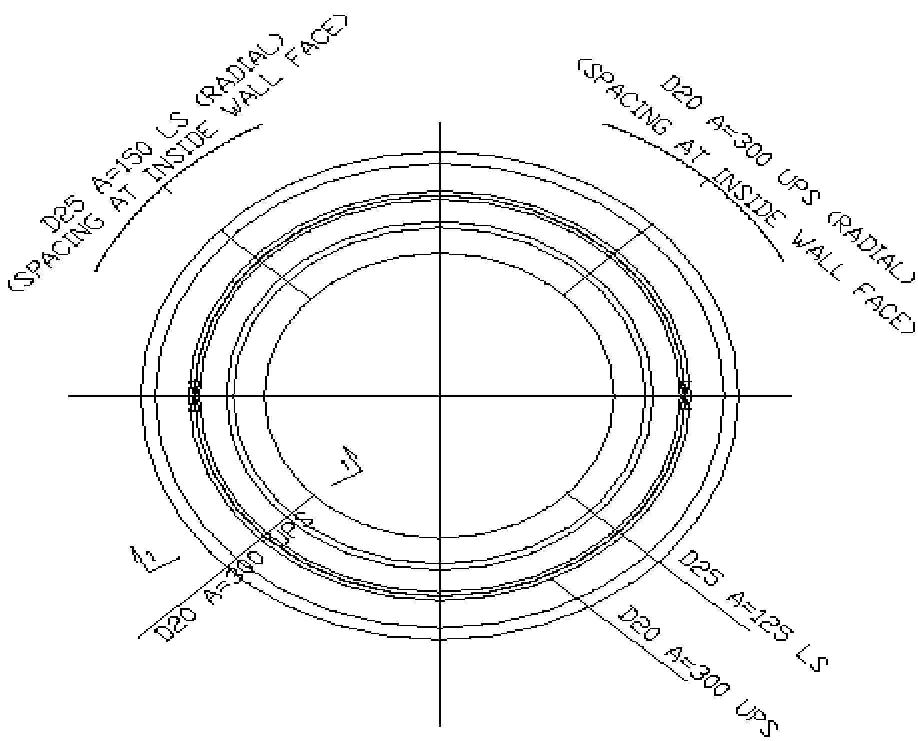

Fig.5: Reinforcement details for Annular raft in plan

5 Conclusion

Based on the study it is concluded that

- Hoop tension increases along the depth from top level.
- Horizontal pressure is more for material emptying condition.
- Temperature reinforcement is more in the top one third portion of silo.

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