Design and Analysis of storage vessel (Silo)

[1]Sandip Patel, [2]Vishant Patel

[1]PG Student, [2]Assistant Professor
Laljibhai Chaturbhai Institute of Technology, Bhandu

***Abstract*: Bulk storage tanks are very important for industrial and agricultural facilities. The value of these tanks to society exceeds by far the economic value of the tanks and their contents. This is because the failure of tanks and their accessories is not limited to the immediate danger to nearby human lives, but also to a large extent leads to serious consequences and very likely to long-term environmental damages. Thus to prevent failure of the silo it must be design properly. This report contents designing of the silo as per various applicable code and standards. The silo is designed for various types of load acting on it e.g. dead load, live load, wind or seismic load, load during filling and discharging of bulk material etc. Stress calculation has been done for Silo having storage capacity of 580 m3 for storing plastic pellets. This include different kind of stresses developed in silo i.e. circumferential stress, axial stress, equivalents stresses. Finally, all stresses are verified by allowable stress values of construction material according to standards. Axial buckling and circumferential buckling stresses are verified as per DIN 18800 part 4 1990.**

***Keywords*: Tall structure, Silo design, Design verification**

Introduction

Silo may be classified as storage structure generally used for storing coal, cement, food grains, and other granular materials. Steel silos may be directly supported at ground level in which case walls are extend to the foundation and the stored material rest either on the foundation or directly on the ground. As an alternate the stored material may be supported by silo bottoms elevated above the ground. Elevated steel silos may be supported by columns directly attached to the shell or by special supporting steel or concrete structural framing. In case of small diameter silos, the metal walls may extend down to the foundation and support the entire structure.

1.2 Types of silos

- a. Cement storage silos
- b. Tower silo
    - Concrete stave silos
    - Low-oxygen tower silos
- c. Bunker silos
- d. Bag silos
- e. Bins
- f. Sand and salt silos
- g. Fabric silos

a. Cement storage silos

Cement can be stored in different types of Silos like Horizontal Mobile Silos, Concrete Silos, and Steel Panel Silos etc. depending upon the requirement of the end user. While Mobile Silos come in a relatively small storage capacity of approximately 90MT of Cement, Concrete Silos can store practically thousands of MT of Cement. A majority of Silos that store more than 5000 MT of Cement are constructed from Concrete.

Tower silo

Storage silos are cylindrical structures, typically 10 to 90 ft (3 to 27 m) in diameter and 30 to 275 ft (10 to 90 m) in height with the slip form and Jump from concrete silos being the larger diameter and taller silos. They can be made of many materials. Wood staves, concrete staves, cast concrete, and steel panels have all been used, and have varying cost, durability, and air tightness tradeoffs. Silos storing grain, cement and woodchips are typically unloaded with air slides or augers.

Bunker silos

Bunker silos are trenches, usually with concrete walls, that are filled and packed with tractors and loaders. The filled trench is covered with a plastic tarp to make it airtight. These silos are usually unloaded with a tractor and loader. They are inexpensive and especially well-suited to very large operations.

d. Bag silos

Bag silos are heavy plastic tubes, usually around 8 to 12 ft (2.4 to 3.6 m) in diameter, and of variable length as required for the amount of material to be stored. They are packed using a machine made for the purpose, and sealed on both ends. They are unloaded using a tractor and loader or skid-steer loader. The bag is discarded in sections as it is torn off. Bag silos require little capital investment. They can be used as a temporary measure when growth or harvest conditions require more space, though some farms use them every year.

e. Bins

A bin is typically much shorter than a silo, and is typically used for holding dry matter such as cement or grain. Grain is often dried in a grain dryer before being stored in the bin. Bins may be round or square, but round bins tend to empty more easily due to a lack of corners for the stored material to become wedged and encrusted.

F.Sand and salt silos

Sand and salt for winter road maintenance are stored in conical dome-shaped silos.

g. Fabric silos

Fabric silos are constructed of a fabric bag suspended within a rigid, structural frame. Polyester based fabrics are often used for fabrication of the bag material, with specific attention given to fabric pore size. Upper areas of silo fabric are often manufactured with slightly larger pore size, with the design intent of acting as a vent filter during silo filling. Some designs include metal thread within the fabric, providing a static conductive path from the surface of the fabric to ground. The frame of a fabric silo is typically constructed of steel. Fabric

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silos are an attractive option because of their relative low cost compared to conventional silos. However, when fabric silos are used to store granular or particulate combustible materials, conventional practices prescribed by established industry consensus standards

1.3 Components of silo

Following are the main components of silo.

- Cylindrical Bin
- Conical Bottom
- Roof
- Short Skirt for support to entire assembly

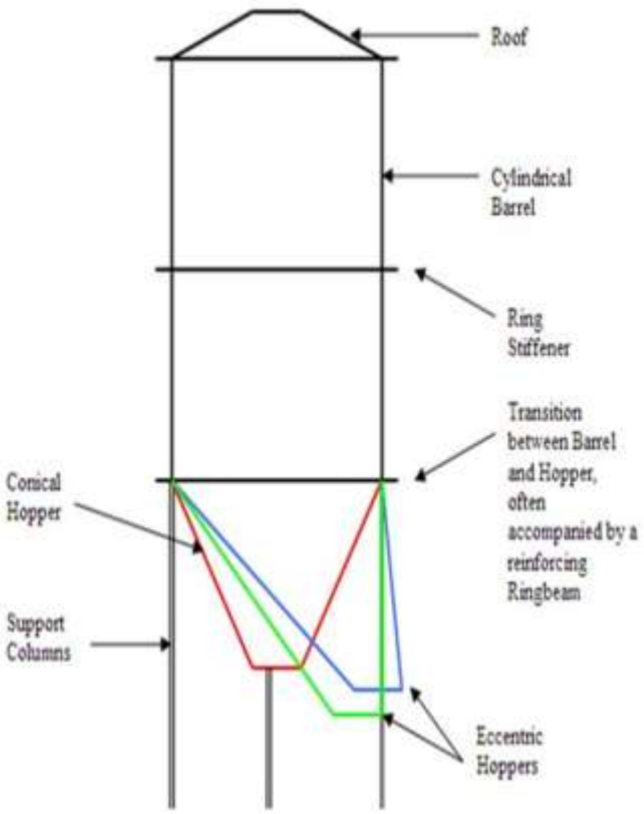

Figure: Silo Components [3]

Classification

For design purposes, bins are classified by their size, geometry, the type of flow during discharge of the contents, and the structural material of the wall. The importance of each of these parameters in design is discussed below.

Bin Size and Geometry

The bin size and geometry depend on the functional requirements such as the storage volume and the method and rate of discharge, the properties of the stored material, available space and economic considerations. Bins usually consist of a vertical sided section with a flat bottom or a bottom with inclined sides, known as the hopper. They are usually circular, square or rectangular in cross-section and may be arranged singly or in groups. Circular bins are more efficient structures than square or rectangular bins, leading to lower material costs. For the same height, a square bin provides more storage than a circular bin whose diameter equals the length of the side of the square bin. Flat- bottom bins require less height for a given volume of stored material. The bin size is determined by feeding and discharge rates and the maximum quantity of material to be stored. High discharge rates require deep hoppers with steep walls. Flat bottomed bins usually have low discharge rates and are used when the storage time is long, the discharge is infrequent and the storage volume is high.

Type of Flow

They are basically two types of flow, mass flow and funnel flow. Discharge pressure is influenced by the flow pattern and so the flow assessment must be made before the calculation of loads from the stored material. The flow type depends on the inclination of the hopper walls and the coefficient of wall friction. Mass flow occurs in deep bins with steep hopper walls whereas funnel flow occurs in squat bins with shallow hopper walls.

1.4.3 Structural Material of the Bin Wall

Most bins are constructed from steel or reinforced concrete. The economic choice depends upon the material costs as well as the costs of fabrication and erection. Other factors such as available space also influence the selection. The main advantages of aluminum bins are resistance to corrosion. The metal walls may require lining to prevent excessive wear, and the metal walls are prone to condensation which may damage stored products such as grain and sugar, etc. which are moisture sensitive. Metal bins, usually carry the lateral forces by hoop tension. They are more prone to failure by buckling under excessive vertical forces

Silo can be further classified are,

a. As per material used

• Concrete silo
• Metal silo

b. As per shapes of the circular bin

• Circular
• Square / Rectangular

c. As per shapes of the bottom

• Hopper bottom (cone /pyramid)
• Flat bottom

Objective of study

The objective of this project is to give a detailed design and analysis of hopper bottom grain storage aluminum silo as per applicable codes and Standards.

- To Modify hopper design.
- To remove RCC columns (A silo with eccentric hopper supported on LLDPE)
- Tests include determination of parameter of the bulk material related with the analysis of explosion
- To reduce weight ratio is 1/3
- To improving long life
- Maintain bulk solid material quality.

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Literature Review

This Chapter described the literature review for the project. Literature review mainly includes stored material pressures calculation, construction procedure, interaction between grains and walls of its storage structure, pressure distributions, design and analysis of the silos.

General

P.Vidal. et al [1] proposed three-dimensional finite element analysis for the filling of cylindrical silos having an eccentric hopper, using different boundary conditions silos supported at the transition or on discrete columns. The analysis included the options of the presence or absence of reinforcement in the transition and walls. The results for the pressures on the wall for a flexible wall and all the boundary conditions were compared with those for a silo with a rigid wall. The membrane stresses and meridional and circumferential bending moments were then evaluated in the silo wall and in the reinforcing elements. The influence of the eccentricity of the hopper in a silo of intermediate eccentricity was analyzed, and conclusions were drawn for the optimal design of these structures

D. Briassoulis [2] have done the analysis of the behavior and the state of stress developing in a silo shell under real asymmetric pressure distributions concerning both storing and discharge. The results obtained suggest that the design of such structures may not neglect the asymmetric features of the real pressures developed by the stored material.

Y. Zhao,J.G.Teng [3] Generally cone cylinder-skirt transition junction is subject to a large circumferential compressive force which is derived from the horizontal component of the meridional tension in the conical hopper, so either a ring is provided or the shell walls are locally thickened to strengthen the junction. Extensive theoretical studies have examined by Y.Zhao and J.G.Teng for the buckling and collapse strengths of these junctions, leading to theoretically based design proposals. They present the results of a series of tests on cone-cylinder-skirt-ring junctions in steel silos under simulated bulk solid loading. In addition to the presentation of test results including geometric imperfections and failure behavior, the determination of buckling modes and loads based on displacement measurements is examined in detail.

Y. Zhao J.G. Teng [4] presented the finite element modeling of the experiments on cone-cylinder- skirt-ring transition junctions in steel silos under simulated bulk solid loading presented in the companion paper. Before presenting the finite element results, the issue of modeling the interaction between the stored solid and the shell wall throughout the loading process is first examined. Results from nonlinear bifurcation analysis using the perfect shapes and nonlinear analysis using the measured imperfect shapes are then presented and compared with the experimental results. These comparisons show that despite the structural complexity of steel silo transition junctions, their behavior can be satisfactorily predicted by finite element analysis considering a number of important factors including geometric imperfections, effects of welding and the interaction between the junction and the stored solid. Next, they present results of nonlinear analysis of these junctions with assumed eigen mode-affine imperfections. These results shed considerable light on the effect of ring buckling on the load-carrying capacity of transition junctions.

F. ayuga et al. [5] has done experimental work on silo which was cylindrical of 1.9 m in diameter and 5 m in height of the vertical wall, with emptying hoppers designed with three different eccentricities. The wall has been made of smooth steel, with enough thickness and reinforcements to be considered rigid. Specially designed sensors have been fixed in these silos, in order to measure the horizontal pressure and the friction force between the wall and the bulk solid. The horizontal pressure cells measure the deflection of a circular thin plate by means of four strain gauges and the friction forces sensor measure the deformation of a small cantilever beam by two strain gauges.

Feat Tinis.et al [6] proposed that cylindrical silo walls are subjected to both normal pressures and vertical friction shear or traction due to stored material inside the silo which vary along the wall. The normal pressure on cylindrical walls cause circumferential stress and the vertical frictional shear will cause cumulative axial compressive stress. Due to complexity of the problem, the finite element and numerical integration techniques are very widely used for buckling and collapse analysis.

C.Y. Song. [7] Investigated the structural behavior of circular steel silos subject to patch loads. The investigations reveal that the patch loads have a great effect on the stress states in the silo from the linear elastic analysis (LA). Geometrical non- linearity and primary pressures have beneficial effect. Fourier decompositions of the two square-shaped patch loads show that the effect of the shape of patch loads de- pends not only on the harmonic index, but also on particular stress component. For a pressure with a lower harmonic index (e.g. cos h, cos 2h), only limited effect was observed for all stress components. A pressure with medium-sized harmonic index (cos 4h, cos 6h) has a great effect on meridional compressive stress, while for higher harmonic index; the effect was significant for von Mises equivalent stress. Buckling analysis with geometrical non-linearity and material non-linearity considered show that the effect of patch loads could be covered by a certain percentage increase of the vertical frictions, if the patch load approach were adequate to represent the non-uniformity of wall pressures in circular flat-bottomed steel silos.

Anjanette al [8] presented different three-dimensional models whose distinguishing feature is the simulation of both stored granular material and silo walls, without resorting to simplifications. The models developed predict the stress state of cylindrical metal silos flat bottomed, subjected to the action of stored granular material in their interior. The behavior assigned to the stored material is elastic, and that assigned to the structure is the classical bilinear elastic-perfectly plastic, typical of metallic materials such as steel. Two geometric parameters are analyzed: height and thickness of the wall. The results obtained from numerical methods (hoop, meridional or vertical, normal and shear stresses) are compared with those obtained via ENV 1993-1-6.

Dr. John W. Carson [9] Silos and bins fail with a frequency which is much higher than almost any other industrial equipment. Sometimes the failure only involves distortion or deformation which, while unsightly does not pose safety or operational hazards in other cases failure involves complete collapse of the structure with accompanying loss of use and even loss of life. The major causes of silo failures are due to shortcomings in one or more three categories.

Failures due to design errors
Failures due to construction errors
Failures due to usage

George G.Chase [10] has presented pressure calculation as per the janssen equations which is acting on the wall of the silo and explain calculation for the cone angle and outlet of cone for Conical hopper design.

Methodology

First of all an exhaustive literature survey has been done and research gaps has been identified. Then various designs and operating parameters have been identified. Include different kind of stresses developed in silo i.e. circumferential stress, axial stress, equivalents stresses. Compression of ANSYS and Experimental Data. All stresses are verified by allowable stress values of construction material according to standards. Axial buckling and circumferential buckling stresses are verified as per DIN 18800 part 4 1990.

Load Consideration

1 Dead load
2 Live load
3 Equipment load
4 Wind load
5 Seismic load
6 Stresses acting in silo
7 Loads from external restraints

Designing of Silo Components

Design inputs

- The specification of the silo to be designed are as follows. Capacity of silo =580 m3
- Material to be stored =LLDPE plastic pellets
- Lower diameter of cone d_a =200 mm
- Angle of inclination of hopper wall= 60 degree
- Angle of internal friction(φ) =28 degree
- Bulk density of material(w) =650 kg/m3
- Filling eccentricity e_f =0 mm
- Discharging eccentricity e_o =0 mm
- Height over ground H_o =7000 mm

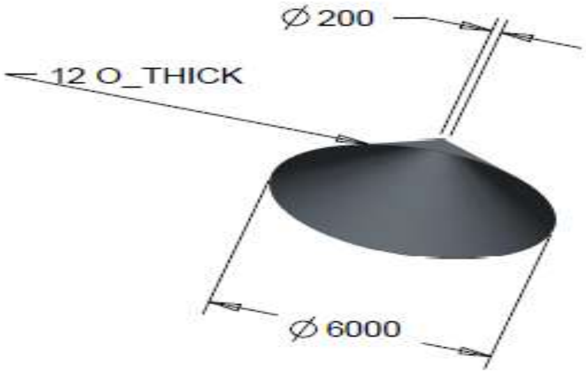

Figure: Hopper

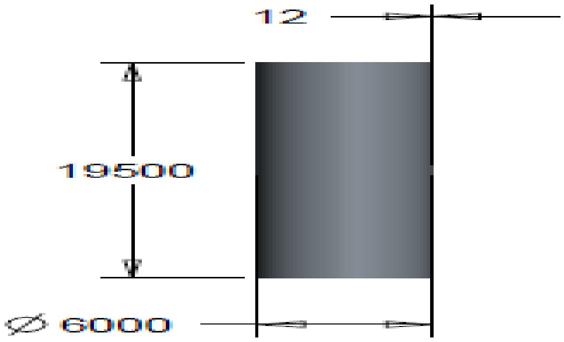

Figure: Bin

Figure: Roof

Designing of cylindrical bin.

Diameter and height selection as per required capacity

D (m)	Capacity/m (m^3)	Tank height in meter/No of course required						
		4.8/2	7.2/3	9.6/4	12/5	14.4/6	16.8/7	19.2/8
3.0	7.07	34	51	68	-	-	-	-
4.5	15.9	76	115	153	191	-	-	-
6.0	28.3	136	204	272	339	407	474	542
7.5	44.2	212	318	424	530	636	742	848
9.0	63.6	305	458	610	763	916	1069	1221

$C = 0.785 \times D^2 \times H$

By trial and error method following parameters are obtained from Table 1 for the silo having 2500 mm Course height and 551 m^3 Capacity.

Diameter of silo =6000 mm,

Height of cylindrical bin =19500 mm,

Volume of cylindrical bin =551 m^3.

Material:EN AW 5754		
Design temperature:	T=80°	Ct=1.00
RP 0.2=80N/mm2	E=70N/mm2	µm=0.75
RP 0.2(T) =80N/mm2	E(T)=68N/mm2	E*(T)=53N/mm2
Safety factors:	LFH:Y=1.70	LFHZ:Y=1.50

Table : Material property for EN AW 5754[14]

Material:EN AW 5083		
Design temperature:	T=80°	C_t=1.00
RP 0.2=125N/mm^2	E=70N/mm^2	μ_m=0.75
RP 0.2(T) =80N/mm^2	E(T)=68N/mm^2	E*(T)=63N/mm^2
Safety factors:	LFH:Y=1.70	LFHZ:Y=1.50

Table 4.3: Material property for EN AW 5083[14]

Sr No	Name of pressure	During filling	During Emptying
1	Maximum Pw	9.75 K N/m^2	9.75 K N/m^2
2	Maximum Ph	25.40 K N/m^2	32.28 K N/m^2
3	Maximum Pv	50.80 K N/m^2	32.28 K N/m^2

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Depth Z Meter	Z/Zof	e−Z/Z of	Xf=1-e−Z/Z of	Pw×Xf	Ph×Xf	Pv×Xf
				kN/m^2	kN/m^2	kN/m^2
1	0.13	0.88	0.12	1.17	3.05	6.10
2	0.26	0.77	0.23	2.24	5.84	11.68
3	0.38	0.68	0.32	3.12	8.13	16.28
4	0.51	0.60	0.40	3.90	10.16	20.32
5	0.64	0.53	0.47	4.58	11.94	23.88
6	0.77	0.46	0.54	5.27	13.72	27.43
7	0.90	0.41	0.59	5.75	14.99	29.97
8	1.02	0.36	0.64	6.24	16.26	32.51
9	1.15	0.32	0.68	6.63	17.27	34.54
10	1.28	0.28	0.72	7.02	18.29	36.58
11	1.41	0.24	0.76	7.41	19.30	38.61
12	1.54	0.21	0.79	7.70	20.07	40.13
13	1.66	0.19	0.81	7.9	20.57	41.18
14	1.79	0.17	0.83	8.09	21.08	42.16
15	1.92	0.15	0.85	8.29	21.59	43.18
16	2.05	0.13	0.87	8.48	22.10	44.20
17	2.18	0.11	0.89	8.68	22.61	45.21
18	2.30	0.10	0.90	8.78	22.86	45.72
19	2.43	0.09	0.91	8.87	23.11	46.23
20	2.56	0.08	0.92	8.97	23.37	46.74
21	2.69	0.07	0.93	9.07	23.62	47.24
22	2.82	0.06	0.94	9.17	23.88	47.75
23	2.94	0.05	0.95	9.26	24.13	48.26

Table-Pressure acting during filling condition

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depth Z meter	Z/Zoe	e−Z/Z oe	Xe=1-e−Z/Z oe	Pw×Xe	Ph×Xe	Pv×Xe
				kN/m^2	kN/m^2	kN/m^2
1	0.20	0.82	0.18	1.76	5.81	5.81
2	0.40	0.67	0.33	3.22	10.65	10.65
3	0.60	0.55	0.45	4.39	14.53	14.53
4	0.81	0.44	0.56	5.46	18.08	18.08
5	1.01	0.36	0.64	6.24	20.66	20.66
6	1.21	0.30	0.70	6.83	22.60	22.60
7	1.41	0.24	0.76	7.41	24.53	24.53
8	1.61	0.20	0.80	7.80	25.82	25.82
9	1.81	0.16	0.84	8.19	27.12	27.12
10	2.01	0.13	0.87	8.48	28.08	28.08
11	2.21	0.11	0.89	8.68	28.73	28.73
12	2.42	0.09	0.91	8.87	29.37	29.37
13	2.62	0.07	0.93	9.07	30.02	30.02
14	2.82	0.06	0.94	9.17	30.34	30.34
15	3.02	0.05	0.95	9.26	30.67	30.67
16	3.22	0.04	0.96	9.36	30.99	30.99
17	3.42	0.03	0.97	9.46	31.31	31.31
18	3.62	0.02	0.97	9.46	31.31	31.31
19	3.83	0.02	0.98	9.56	31.63	31.63
20	4.03	0.01	0.98	9.56	31.63	31.63
21	4.23	0.01	0.99	9.65	31.96	31.96
22	4.43	0.01	0.99	9.65	31.96	31.96
23	4.63	0.01	0.99	9.65	31.96	31.96

Table: Pressure acting during emptying condition

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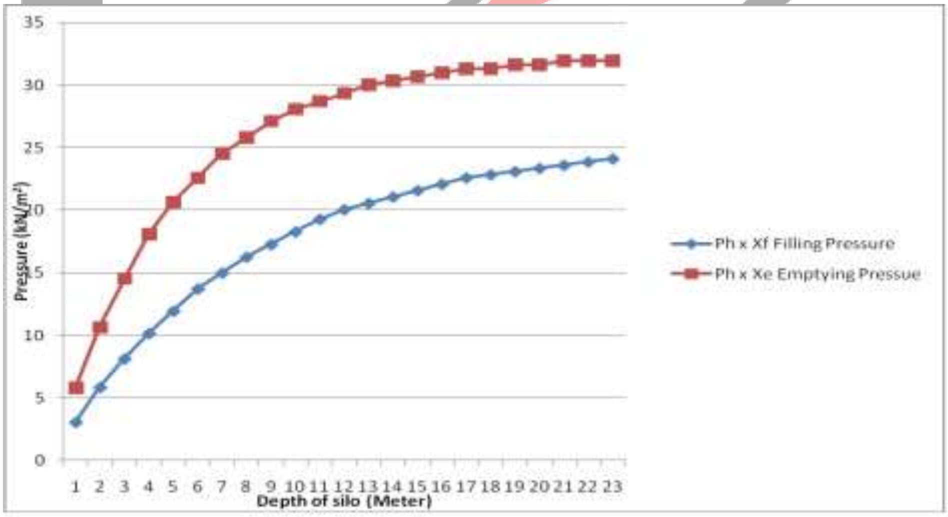

Figure 6: Wall frictional pressure during filling and emptying

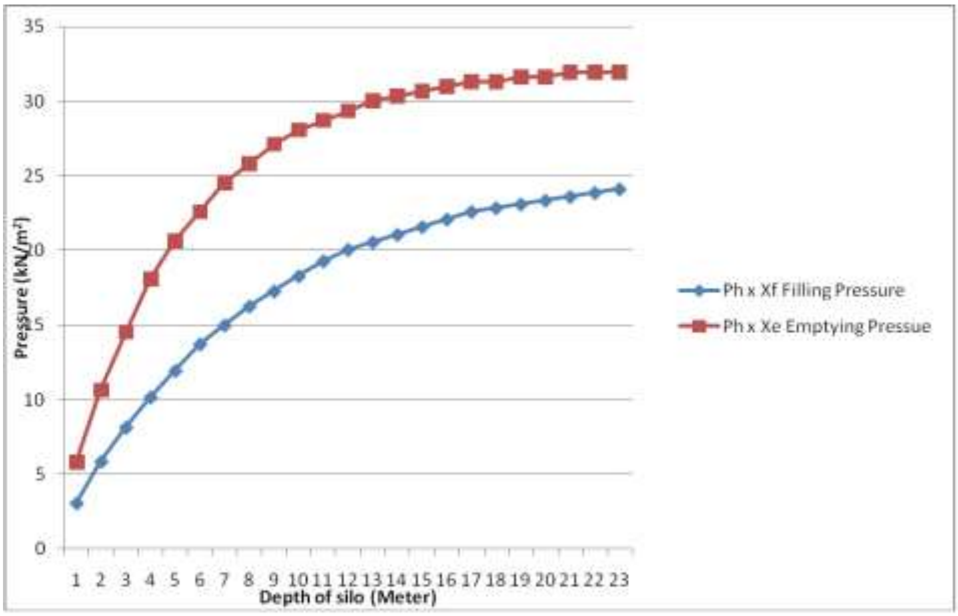

Figure 7: Horizontal pressure during filling and emptying

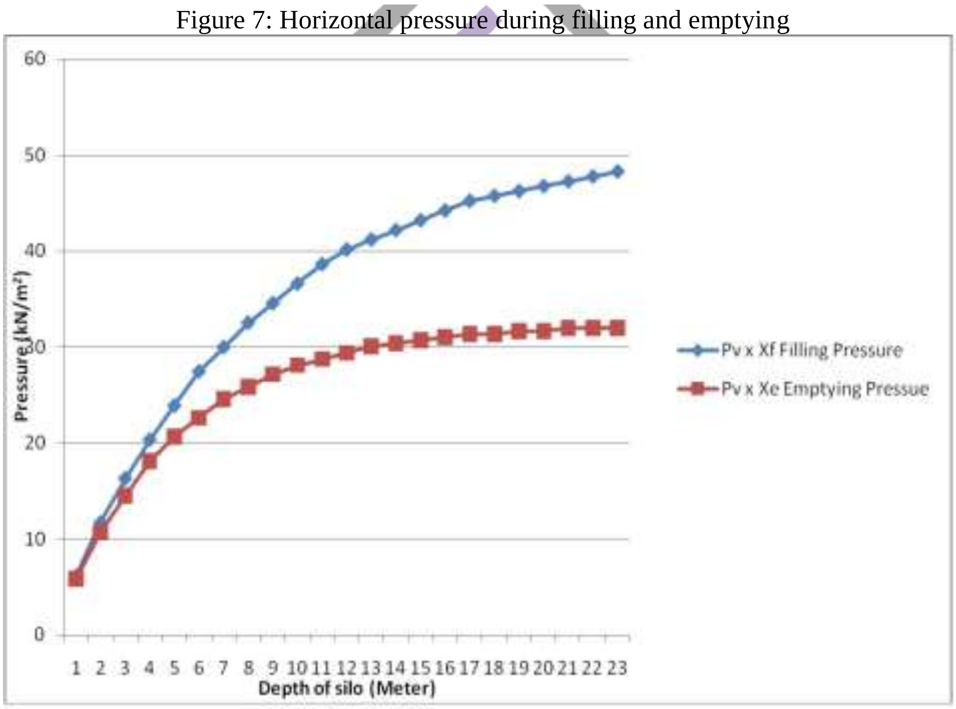

Figure : Vertical pressure during filling and emptying

[Nos]	h_i [mm]	P_v [M_{pa}]	P_h [M_{pa}]	t_d [mm]	t_{min} [mm]	t_{act} [mm]
1	2500	0.016	0.014	3.937	5	5
2	5000	0.032	0.028	4.874	5	5
3	7500	0.048	0.042	5.811	5	6
4	10000	0.064	0.056	6.747	5	7
5	12500	0.080	0.070	7.683	5	8
6	15000	0.096	0.084	8.619	5	9
7	17500	0.112	0.099	9.555	5	10
8	19500	0.127	0.113	10.490	5	12

Table : Shell thickness calculation

section	t(mm)	h(mm)	G(kN)
1	5	2.5	6.35
2	5	2.5	6.35
3	6	2.5	6.90
4	7	2.5	7.63
5	8	2.5	10.17
6	9	2.5	11.40
7	10	2.5	12.55
8	12	2.0	12.21

Table : Dead load for cylindrical bin

Sectio	n T	h(z)	h	D	Phwind	Ap	Hw,i	Mw,i,o
	[m]	[m]	[m]	[m]	[kN/m2]	[m2]	[kN]	[kN.m]
1	5	24.5	2.5	6	0.876	15	13.14	321.93
2	5	22	2.5	6	0.876	15	13.14	289.08
3	6	19.5	2.5	6	0.806	15	12.09	235.755
4	7	17	2.5	6	0.806	15	12.09	205.53
5	8	14.5	2.5	6	0.806	15	12.09	175.305
6	9	12	2.5	6	0.806	15	12.09	145.08
7	10	9.5	2.5	6	0.707	15	10.605	100.748
8	12	7.5	2	6	0.707	12	8.484	63.63

Table: Moment due to wind on vertical wall Segments

Thickness calculation for conical bottom

Conical bottom design has been done as per ASME SEC VIII DIVI. Thickness of various section of the cone can be obtained based on maximum internal pressure. Internal Pressure (P) =0.140 Mpa
Diameter (D) =6000 mm

Half apex angle (α)=30 degree Material stress value(S)=60 Mpa Joint efficiency(E)=0.6
Required thickness due to internal Pressure

$$tc = \frac{p \times d}{2 \times \cos\alpha \times (S \times E - 0.6 \times P)}$$

Calculated conical bottom thickness for three section. Top section thickness tC 1=12mm
Middle section thickness t_C 2=8mm

Bottom thickness t_C 3=6mm

Sr No	t	hh	x	x/hh	Diameter	Pvf	Pnf	Ptf
1	12	5.02	5.02	1.00	6000.00	72.37	70.42	6.51
2	12	5.02	4.5	0.90	5422.37	57.95	71.57	6.62
3	12	5.02	4	0.80	4844.82	45.91	72.42	6.70
4	12	5.02	3.5	0.70	4246.93	35.55	72.96	6.75
5	8	5.02	3	0.60	3689.24	26.78	73.12	6.76
6	8	5.02	2.5	0.50	3105.78	19.48	72.77	6.73
7	8	5.02	2	0.40	2531.36	13.52	71.71	6.63
8	6	5.02	1.5	0.30	1956.18	8.77	69.60	6.44
9	6	5.02	1	0.20	1378.49	5.07	65.71	6.08
10	6	5.02	0.5	0.10	800.80	2.23	57.97	5.36

Table: Pressure in conical bottom due to filling

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Sr No	t	h_h	x	x/h_h	Diameter	Pve	Pne	Pte
1	12	5.02	5.02	1.00	6000.00	72.37	140.40	6.51
2	12	5.02	4.5	0.90	5422.37	57.95	112.43	5.22
3	12	5.02	4	0.80	4844.82	45.91	89.07	4.13
4	12	5.02	3.5	0.70	4246.93	35.55	68.98	3.20
5	8	5.02	3	0.60	3689.24	26.78	51.96	2.41
6	8	5.02	2.5	0.50	3105.78	19.48	37.78	1.75
7	8	5.02	2	0.40	2531.36	13.52	26.22	1.22
8	6	5.02	1.5	0.30	1956.18	8.77	17.01	0.79
9	6	5.02	1	0.20	1378.49	5.07	9.83	0.46
10	6	5.02	0.5	0.10	800.80	2.23	4.33	0.20

Table: Pressure in conical bottom due to discharging

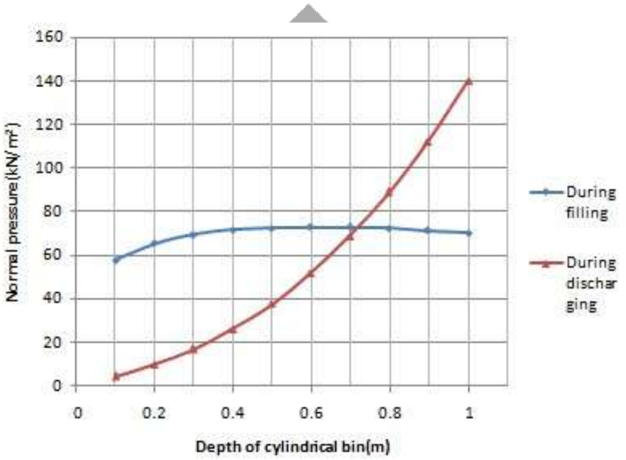


Figure : Normal pressure during filling and discharging

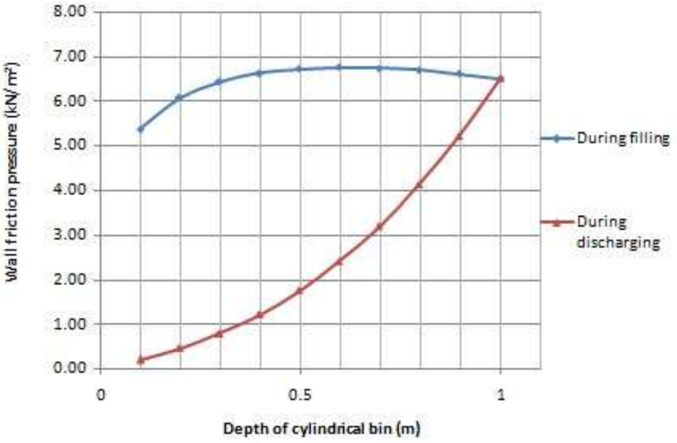


Figure : Wall frictional pressure during filling and discharging

Stresses in cylindrical bin

Section	t	z	Phe	Phi	Ph	Nphi	σphi
	[mm]	[m]	[kN/m2]	[kN/m2]	[kN/m2]	[kN/m]	[Mpa]
1	5	2.5	10.65	4.5	15.15	45.45	9.09
2	5	5	20.66	4.5	25.16	75.48	15.1
3	6	7.5	25.82	4.5	30.32	90.96	18.19
4	7	10	28.08	4.5	24.58	73.74	12.29
5	8	12.5	30.02	4.5	34.52	103.56	12.95
6	9	15	30.99	4.5	35.49	106.47	11.83
7	10	17.5	31.31	4.5	35.81	107.43	9.03
8	12	19.5	31.63	4.5	36.13	108.49	9.03

Table : Tensile circumferential stress.(during discharge)

Shell Sec- tion	t	h	Z	Phwind	nphi	Σphi
	[mm]	[m]	[m]	[kN/m2]	[kN/m]	[Mpa]
1	5	24.5	2.5	0.876	2.628	0.5256
2	5	22	5	0.876	2.628	0.5256
3	6	19.5	7.5	0.806	2.418	0.4836
4	7	17	10	0.806	2.418	0.403
5	8	14.5	12.5	0.806	2.418	0.30225
6	9	12	15	0.806	2.418	0.26867
7	10	9.5	17.5	0.707	2.121	0.19282
8	12	7.5	19.5	0.707	2.121	0.17675

Table : Compressive Stress due to wind Pressure

Shell Sec- tion	t	h	Z	Ph min.	nphi	Σphi
	[mm]	[m]	[m]	[kN/m2]	[kN/m]	[N/mm2]
1	5	24.5	2.5	-0.5	1.5	0.3
2	5	22	5	-0.5	1.5	0.3
3	6	19.5	7.5	-0.5	1.5	0.3
4	7	17	10	-0.5	1.5	0.25
5	8	14.5	12.5	-0.5	1.5	0.1875
6	9	12	15	-0.5	1.5	0.16667
7	10	9.5	17.5	-0.5	1.5	0.13636
8	12	7.5	19.5	-0.5	1.5	0.125

Table: Compressive Stress due to discharging

Shell section	Plate thick- ness [mm]	Depth [m]	Resulting tensile force [kN/m]	Axial stress [MPa]	Allowable stress [MPa]	Utilization coefficient
	t	z	Nx	σmax	Σzul	σmax / σzul
1	5	2.5	8.92	1.78	45.9	0.038
2	5	5	13.41	2.68	45.9	0.058
3	6	7.5	19.96	3.99	45.9	0.086
4	7	10	28.57	4.76	45.9	0.103
5	8	12.5	39.19	4.89	45.9	0.106
6	9	15	51.89	5.76	45.9	0.125
7	10	17.5	65.68	5.97	45.9	0.13
8	12	19.5	78	6.5	45.9	0.141
					Max = 0.1416	

Table : tensile axial stress (Dead Load + Wind Load + Over pressure)

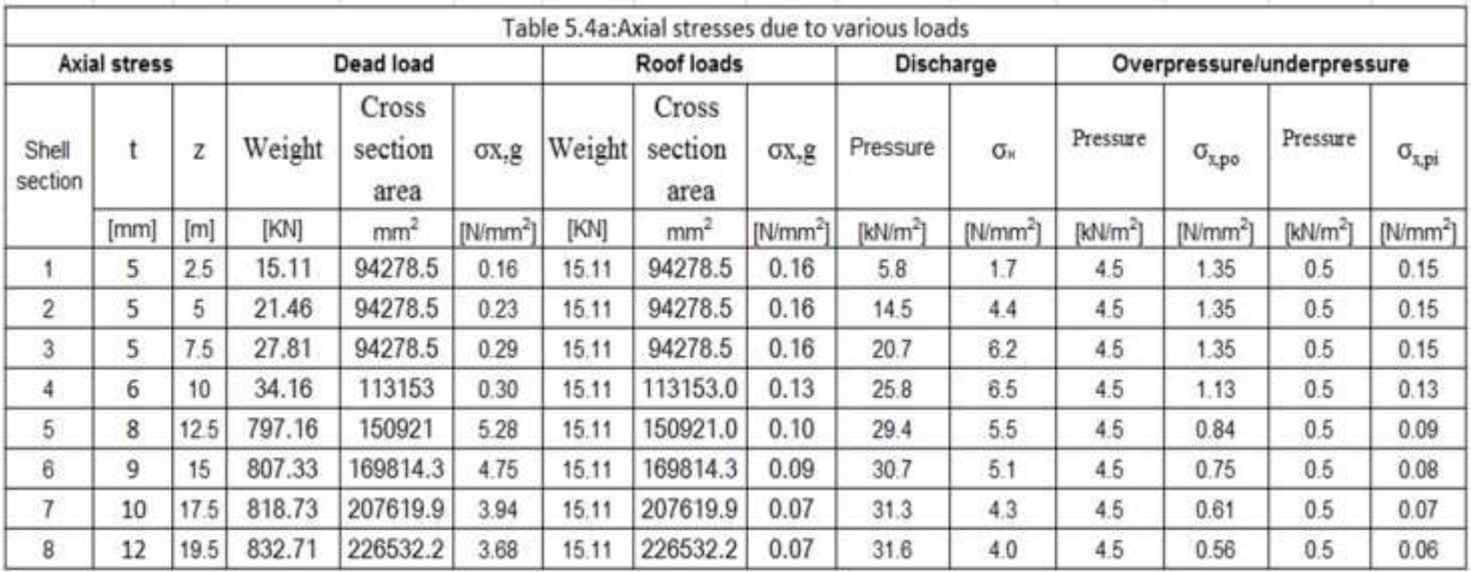


Table 5.4a:Axial stresses due to various loads

Axial stress			Dead load			Roof loads			Discharge		Overpressure/underpressure			
Shell section	t	z	Weight	Cross section area	σx,g	Weight	Cross section area	σx,g	Pressure	σ_x	Pressure	$\sigma_{x,po}$	Pressure	$\sigma_{x,pi}$
	[mm]	[m]	[KN]	mm^2	[N/mm^2]	[KN]	mm^2	[N/mm^2]	[kN/m^2]	[N/mm^2]	[kN/m^2]	[N/mm^2]	[kN/m^2]	[N/mm^2]
1	5	2.5	15.11	94278.5	0.16	15.11	94278.5	0.16	5.8	1.7	4.5	1.35	0.5	0.15
2	5	5	21.46	94278.5	0.23	15.11	94278.5	0.16	14.5	4.4	4.5	1.35	0.5	0.15
3	5	7.5	27.81	94278.5	0.29	15.11	94278.5	0.16	20.7	6.2	4.5	1.35	0.5	0.15
4	6	10	34.16	113153	0.30	15.11	113153.0	0.13	25.8	6.5	4.5	1.13	0.5	0.13
5	8	12.5	797.16	150921	5.28	15.11	150921.0	0.10	29.4	5.5	4.5	0.84	0.5	0.09
6	9	15	807.33	169814.3	4.75	15.11	169814.3	0.09	30.7	5.1	4.5	0.75	0.5	0.08
7	10	17.5	818.73	207619.9	3.94	15.11	207619.9	0.07	31.3	4.3	4.5	0.61	0.5	0.07
8	12	19.5	832.71	226532.2	3.68	15.11	226532.2	0.07	31.6	4.0	4.5	0.56	0.5	0.06

Stress verification

Sectio	n 1	2	3	4	5	6	7	8
Σphi	4.17	4.20	9.40	9.17	7.60	7.23	6.19	5.83
Σx	2.09	3.60	4.70	4.58	3.80	3.61	3.10	2.91

Table : Stresses in shell during filling

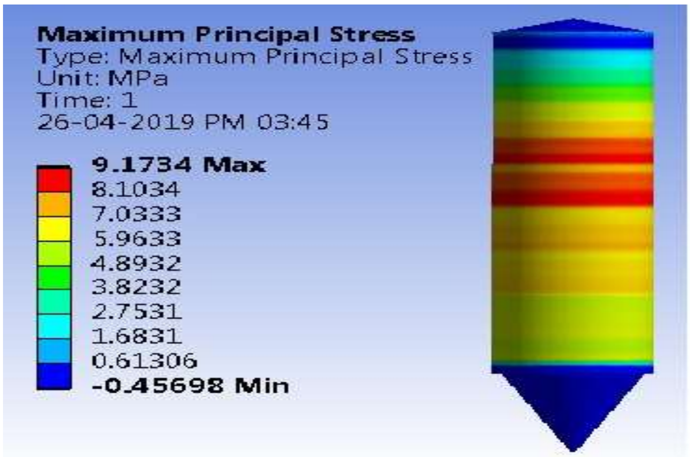


Figure: Maximum principal stress(MPa) in shell during filling

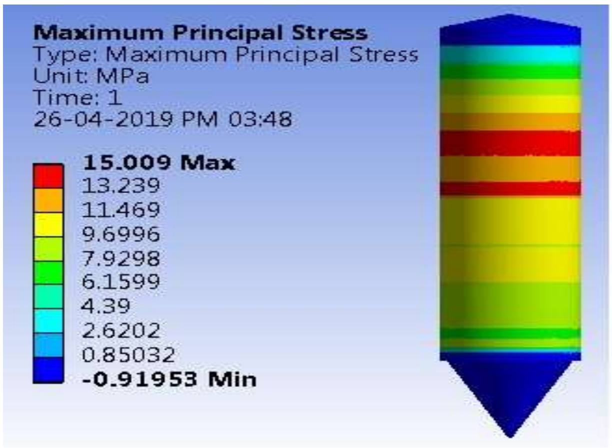


Figure: Maximum principal stress(MPa) in shell during discharge

Stresses in shell during discharge

Sectio	n 1	2	3	4	5	6	7	8
σphi	7.66	12.3	15.1	13.99	11.14	10.24	8.5	7.92
Σx	3.83	6.15	7.55	7	5.57	5.12	4.28	3.96

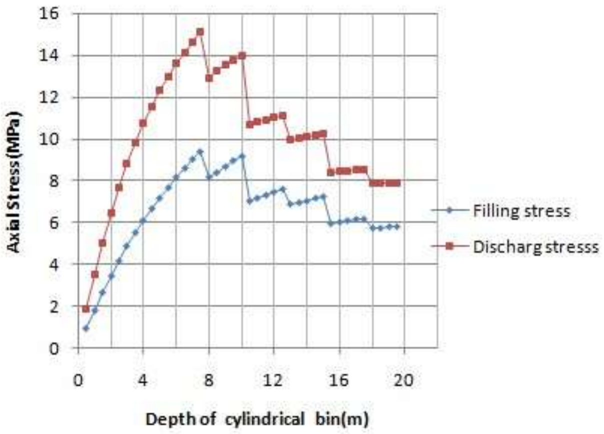


Figure : Axial stresses on shell wall during filling and discharge

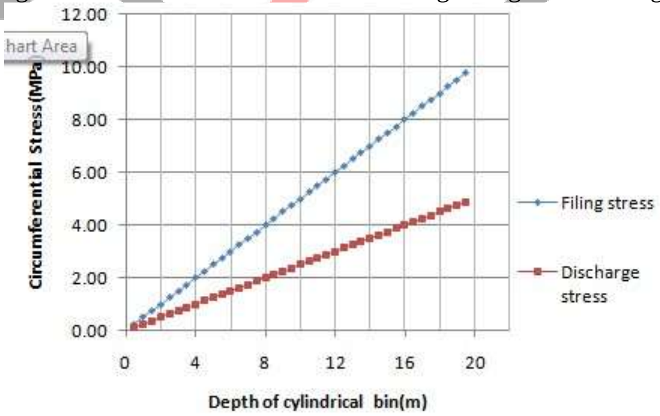
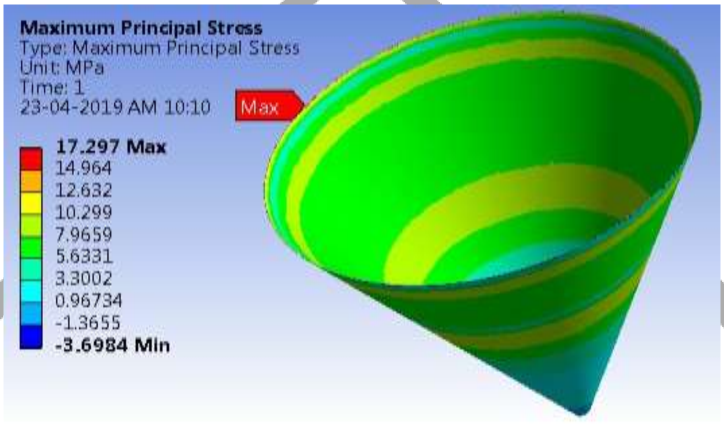


Figure: Circumferential stresses on shell wall during filling and discharge

Stresses in cone during filling

Sr No	t	hh	x	x/hh	Diameter	Pvf	Pnf	Ptf	Σxf	σP hi,f
1	12	5.02	5.02	1.00	6000.00	72.37	70.42	6.51	17.60	8.80
2	12	5.02	4.5	0.90	5422.37	57.95	71.57	6.62	16.17	8.08
3	12	5.02	4	0.80	4844.82	45.91	72.42	6.70	14.62	7.31
4	12	5.02	3.5	0.70	4246.93	35.55	72.96	6.75	12.91	6.46
5	8	5.02	3	0.60	3689.24	26.78	73.12	6.76	16.86	8.43
6	8	5.02	2.5	0.50	3105.78	19.48	72.77	6.73	14.12	7.06
7	8	5.02	2	0.40	2531.36	13.52	71.71	6.63	11.34	5.67
8	6	5.02	1.5	0.30	1956.18	8.77	69.60	6.44	11.35	5.67
9	6	5.02	1	0.20	1378.49	5.07	65.71	6.08	7.55	3.77
10	6	5.02	0.5	0.10	800.80	2.23	57.97	5.36	3.87	1.93

Table : Filling pressure in conical bottom



Maximum principal stress(MPa) in cone during filling

Stresses in cone during discharging

Sr No	t	hh	x	x/hh	Diameter	Pve	Pne	Pte	σX e	σP hi,e
1	12	5.02	5.02	1.00	6000.00	72.37	140.40	6.51	35.10	17.55
2	12	5.02	4.5	0.90	5422.37	57.95	112.43	5.22	25.40	12.70
3	12	5.02	4	0.80	4844.82	45.91	89.07	4.13	17.98	8.99
4	12	5.02	3.5	0.70	4246.93	35.55	68.98	3.20	12.21	6.10
5	8	5.02	3	0.60	3689.24	26.78	51.96	2.41	11.98	5.99
6	8	5.02	2.5	0.50	3105.78	19.48	37.78	1.75	7.33	3.67
7	8	5.02	2	0.40	2531.36	13.52	26.22	1.22	4.15	2.07
8	6	5.02	1.5	0.30	1956.18	8.77	17.01	0.79	2.77	1.39
9	6	5.02	1	0.20	1378.49	5.07	9.83	0.46	1.13	0.56
10	6	5.02	0.5	0.10	800.80	2.23	4.33	0.20	0.29	0.14

Table : Discharge pressure in conical bottom

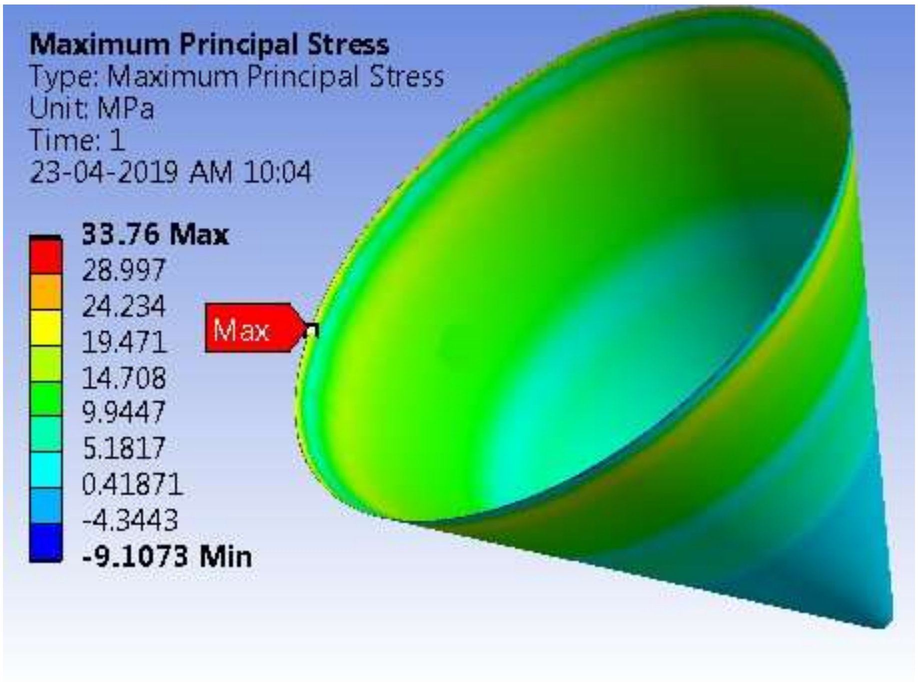


Figure : Maximum principal stress(MPa) in cone during discharge

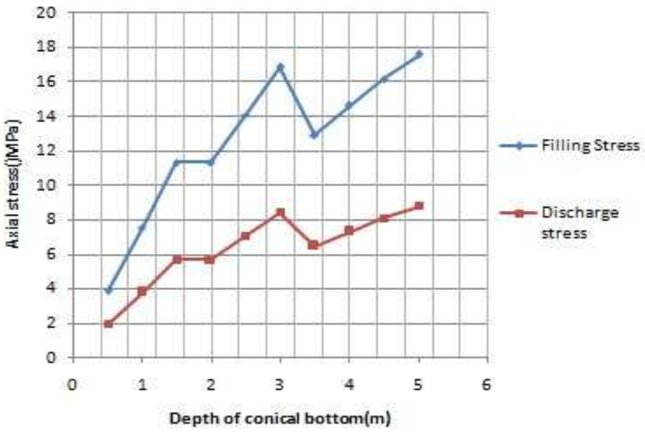


Figure: Axial stresses on cone wall during filling and discharge

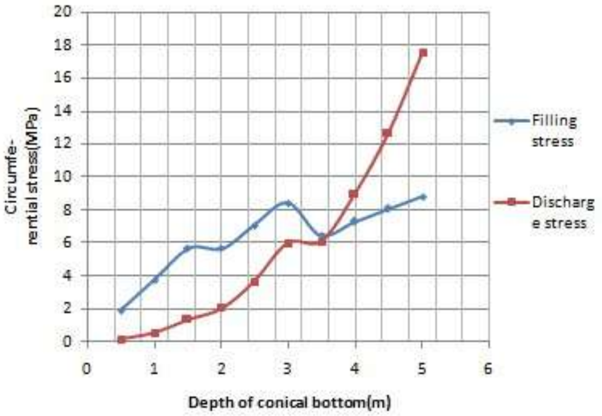


Figure: Circumferential stresses on cone wall during filling and discharge

Buckling Verification

Figure : Circumferential buckling

Figure : Axial buckling

DIN 18800 part 4 deals with the analysis of the buckling resistance of steel shell structures. This standard specifies rules relating to the stability of un stiffened shells susceptible to buckling. For safe design against shell buckling following load or com- bination of the load should be verified.

- Resistance to buckling under axial compression
- Resistance to buckling under external pressure (wind or vacuum)
- Resistance to buckling under shear from unsymmetrical actions

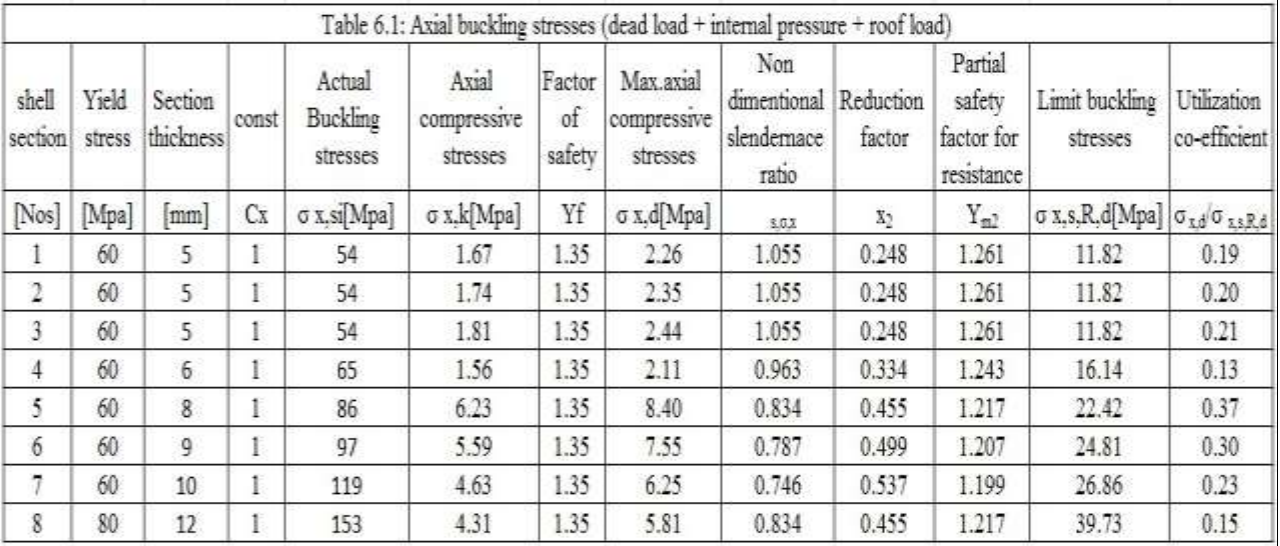


Table 6.1: Axial buckling stresses (dead load + internal pressure + roof load)

shell section	Yield stress	Section thickness	const	Actual Buckling stresses	Axial compressive stresses	Factor of safety	Max.axial compressive stresses	Non dimentional slendernace ratio	Reduction factor	Partial safety factor for resistance	Limit buckling stresses	Utilization co-efficient
[Nos]	[Mpa]	[mm]	Cx	σ x,si[Mpa]	σ x,k[Mpa]	Yf	σ x,d[Mpa]	$_{s,\sigma,x}$	x_2	Y_{m2}	σ x,s,R,d[Mpa]	$\sigma_{x,d}/\sigma_{x,s,R,d}$
1	60	5	1	54	1.67	1.35	2.26	1.055	0.248	1.261	11.82	0.19
2	60	5	1	54	1.74	1.35	2.35	1.055	0.248	1.261	11.82	0.20
3	60	5	1	54	1.81	1.35	2.44	1.055	0.248	1.261	11.82	0.21
4	60	6	1	65	1.56	1.35	2.11	0.963	0.334	1.243	16.14	0.13
5	60	8	1	86	6.23	1.35	8.40	0.834	0.455	1.217	22.42	0.37
6	60	9	1	97	5.59	1.35	7.55	0.787	0.499	1.207	24.81	0.30
7	60	10	1	119	4.63	1.35	6.25	0.746	0.537	1.199	26.86	0.23
8	80	12	1	153	4.31	1.35	5.81	0.834	0.455	1.217	39.73	0.15

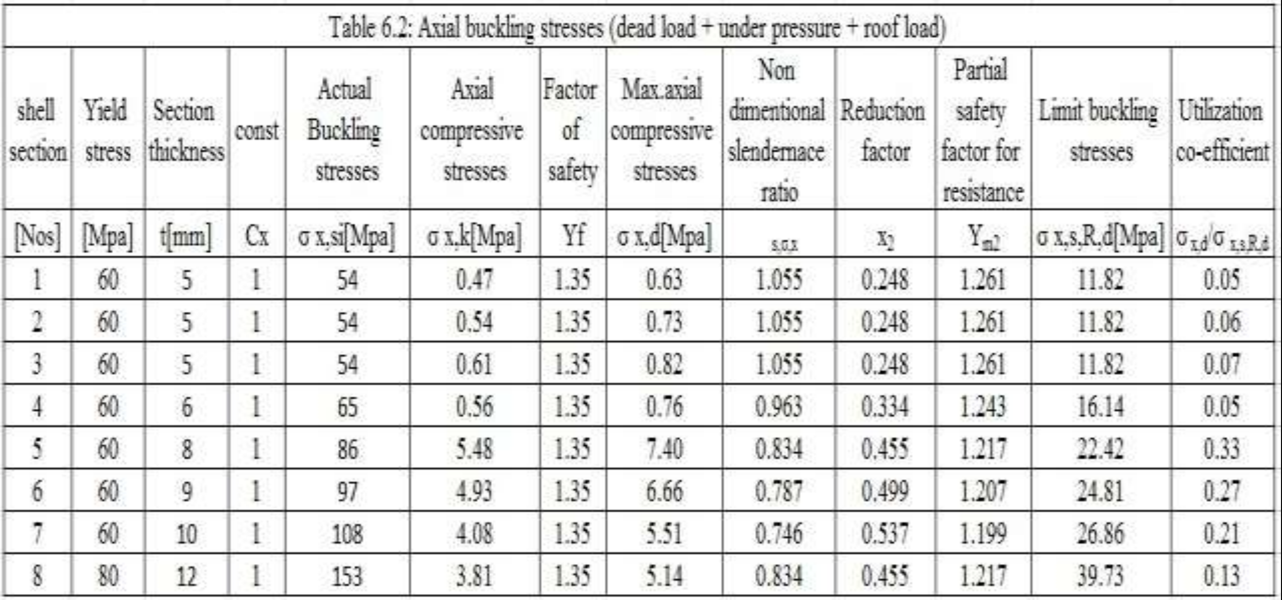


Table 6.2: Axial buckling stresses (dead load + under pressure + roof load)

shell section	Yield stress	Section thickness	const	Actual Buckling stresses	Axial compressive stresses	Factor of safety	Max.axial compressive stresses	Non dimentional slendernace ratio	Reduction factor	Partial safety factor for resistance	Limit buckling stresses	Utilization co-efficient
[Nos]	[Mpa]	t[mm]	Cx	σ x,si[Mpa]	σ x,k[Mpa]	Yf	σ x,d[Mpa]	$_{s,\sigma,x}$	x_2	Y_{m2}	σ x,s,R,d[Mpa]	$\sigma_{x,d}/\sigma_{x,s,R,d}$
1	60	5	1	54	0.47	1.35	0.63	1.055	0.248	1.261	11.82	0.05
2	60	5	1	54	0.54	1.35	0.73	1.055	0.248	1.261	11.82	0.06
3	60	5	1	54	0.61	1.35	0.82	1.055	0.248	1.261	11.82	0.07
4	60	6	1	65	0.56	1.35	0.76	0.963	0.334	1.243	16.14	0.05
5	60	8	1	86	5.48	1.35	7.40	0.834	0.455	1.217	22.42	0.33
6	60	9	1	97	4.93	1.35	6.66	0.787	0.499	1.207	24.81	0.27
7	60	10	1	108	4.08	1.35	5.51	0.746	0.537	1.199	26.86	0.21
8	80	12	1	153	3.81	1.35	5.14	0.834	0.455	1.217	39.73	0.13

Table:6.3:Circumferential buckling calculation (dead load + roof loads + wind loads)

section	Thickness	Yield stress	Actual Buckling stresses	Circumferential compressive stresses	Factor of safety	Max.circumf -erential compressive stresses	Non dimentional slendernace ratio	Reduction factor	Partial safety factor for resistance	Limit buckling stresses	Utilization co-efficient
[Nos]	t[mm]	[Mpa]	$\sigma_{\phi,si}$[Mpa]	$\sigma_{\phi,k}$[Mpa]	Y_f	$\sigma_{\phi,d}$[Mpa]	$_{s,\sigma,\phi}$	x_1	Y_{m1}	$\sigma_{\phi,s,R,d}$[Mpa]	$\sigma_{\phi,d}/\sigma_{\phi,s,R,d}$
1	5	60	1.58	0.23	1.5	0.34	6.15	0.02	1.1	0.94	0.36
2	5	60	1.58	0.23	1.5	0.34	6.15	0.02	1.1	0.94	0.36
3	5	60	1.58	0.18	1.5	0.28	6.15	0.02	1.1	0.94	0.29
4	6	60	1.32	0.15	1.5	0.23	6.74	0.01	1.1	0.78	0.29
5	8	60	0.99	0.11	1.5	0.17	7.78	0.01	1.1	0.59	0.29
6	9	60	0.88	0.10	1.5	0.15	8.26	0.01	1.1	0.52	0.29
7	10	60	0.79	0.06	1.5	0.08	8.70	0.01	1.1	0.47	0.18
8	12	80	0.66	0.05	1.5	0.08	11.01	0.01	1.1	0.39	0.20

Table:6.4:Circumferential buckling calculation (dead load + roof loads + wind loads + underpressure)

section	Thickness	Yield stress	Actual Buckling stresses	Circumferential compressive stresses	Factor of safety	Max.circumf -erential compressive stresses	Non dimentional slendernace ratio	Reduction factor	Partial safety factor for resistance	Limit buckling stresses	Utilization co-efficient
[Nos]	t[mm]	[Mpa]	$\sigma_{\phi,si}$[Mpa]	$\sigma_{\phi,k}$[Mpa]	Y_f	$\sigma_{\phi,d}$[Mpa]	$_{s,\sigma,\phi}$	x_1	Y_{m1}	$\sigma_{\phi,s,R,d}$[Mpa]	$\sigma_{\phi,d}/\sigma_{\phi,s,R,d}$
1	5	60	1.58	0.53	1.5	0.79	6.15	0.02	1.1	0.94	0.84
2	5	60	1.58	0.53	1.5	0.79	6.15	0.02	1.1	0.94	0.84
3	5	60	1.58	0.48	1.5	0.73	6.15	0.02	1.1	0.94	0.77
4	6	60	1.32	0.40	1.5	0.60	6.74	0.01	1.1	0.78	0.77
5	8	60	0.99	0.30	1.5	0.46	7.78	0.01	1.1	0.59	0.78
6	9	60	0.88	0.27	1.5	0.41	8.26	0.01	1.1	0.52	0.78
7	10	60	0.79	0.20	1.5	0.29	8.70	0.01	1.1	0.47	0.63
8	12	80	0.66	0.18	1.5	0.27	11.01	0.01	1.1	0.39	0.70

Conclusion

Designing of the silo components have been done using applicable codes and standards. Design load and pressure calculation has been done for cylindrical bin and conical hopper. Verification of circumferential, axial and equivalent stresses have been carried out considering dead load, live load, wind load and load due to filling and dis- charging pressure of the bulk material. Stresses in cylindrical bin and hopper have been obtained with help of FE analysis for pressure variation during filling and discharging condition and same has been compared with theoretical calculation. Verification of buckling resistance for the cylindrical bin has been done using applicable codes.

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