ANALYSIS AND DESIGN OF A MULTI COMPARTMENT CENTRAL CONE CEMENT STORING SILO

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Abstract

Silos have been used since a very long time for the purpose of storage of various materials such as wheat, rice husk, cement and fly ash. They have been proved to be very effective in the process of storing materials and hence grew in demand as the industry progressed. But one of the major constraints faced by storage structures all throughout the world, is its increased rate of failures. This has been accounted to various reasons such as wrong computations of the analytical pressures acting on the walls of the silo and the effect of the entire pressure of the stored material on the base or hopper region of the silo. To counter this, certain inclusions were made to the structure, namely multi compartments and a central cone. Through the analysis of the structure after the inclusion of the internal cone and multi compartments, it is seen that the stresses act in a uniform manner throughout the structure and are also within the permissible range of -1.59 N/mm^2 to -0.181 N/mm^2. Further, by the introduction of multi compartments in the silo and an internal inverted cone, pressure is uniformly distributed throughout the structure, which prevents an excess of pressure in any one particular area of the silo which causes it to fail. Design of the various components of the silo such as external walls, internal multi compartment internal walls, ring beam, internal cone and mat foundation, considering the critical moments and critical pressures obtained from the analysis.

Keywords: *Analytical Pressures, Central Cone, Ring Beam, External Walls, Multi compartment internal walls, Critical Moments, Critical Pressures*

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1. INTRODUCTION

The word silo, derived from the Greek word – *siros*, which means pit for holding grain, is a structure for storing bulk 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. These silos have been modified to accommodate the upcoming cement industry and various alterations have been made to the silo for better storage of materials and for the reduction in the rate of silo failures.

There are three types of silos are in widespread use today: 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. One such innovation, which has proved to have a high success rate is the multi-compartment silo, in this type of silo provision for the storage of different kinds of materials in the same silo has been made available which not only reduces the usage of space used but also makes the silo more economical. Another new design that has been introduced lately in the silo design is the internal or central cone. Most of the conventional silos that are normally seen have a cylindrical body and a hopper bottom, but in an internal cone silo the main difference is this cone is present inside the structure of the silo and does not hopper out.

There are many advantages to this particular type of silo such as the reduction of pressure acting on the base of the silo when the material is in motion. The uniformity in pressures is observed in this type of silos because of the inclusion of the multi compartment walls which help to distribute the hoop stress and longitudinal stress acting on the walls of the silo structure. This feature enhances the safety of the structure and prevents high rates of failure. The internal cone has also contributed to enhancing the safety of the silo. 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 internal cone silo and the benefits of its kind.

2. METHODOLOGY

The basic sequence of activities that have been followed start from the selection of a suitable site area which can hold the entire area of the silo. Following this is the planning which includes the specifications of measurements of the various components. Analysis and design of the structure is done for the various components such as internal and external walls, central cone, ring beam and columns present in the structure. These results are analyzed and discussed and the needful are done to reduce the rate of failure of silos.

2.1 Planning

The following section includes the detailed analysis and design of the silo and its various components and the procedures and methodologies involved above. The various code books are also involved in the design procedures and have been mentioned. An appropriate site corresponding to all the requirements have been chosen. After initializing calculations, the silo dimensions have been found and finalized and shown below in Fig-1.

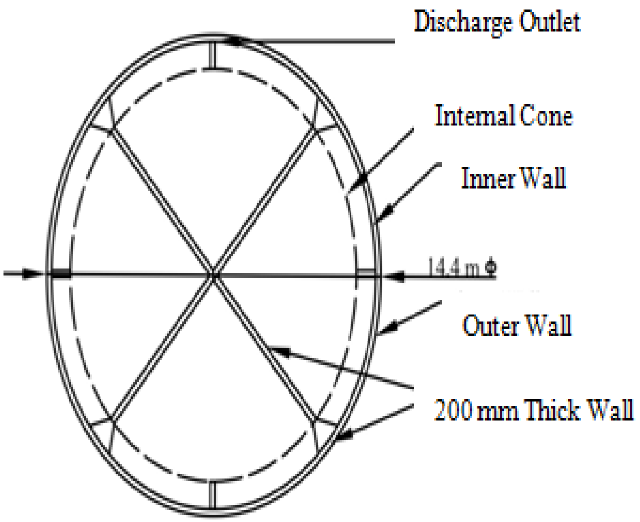

Fig-1: Plan of the Silo

The sectional elevation of the silo is as given in Fig-2 where a detailed demarcation is made between the various components such as the central cone, the silo walls, storage unit etc.

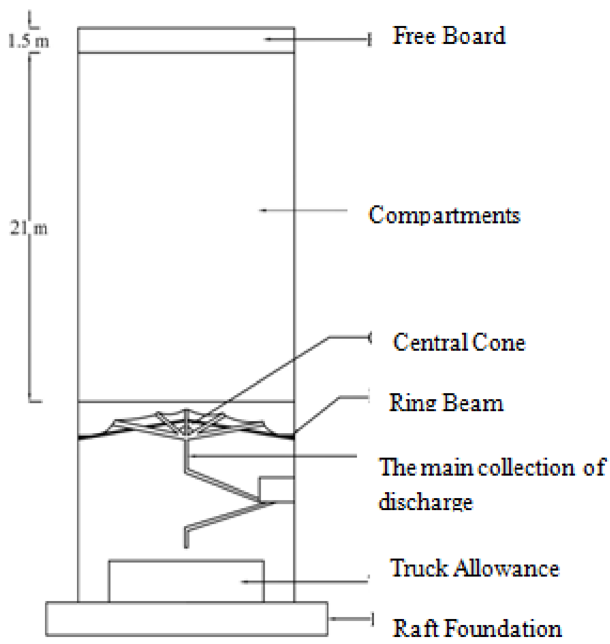

Fig-2: Sectional Elevation of Silo

2.2 Study Area Details

An appropriate site has been selected 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 carefully proportioned, highly accurate blends of quality materials including blended cement and Portland cement manufactured under controlled conditions assuring reliable performance and providing consistent quality.

The highest temperature is obtained in early May to early June usually about 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 zone 3 as the site is located in 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 a latitude of 10°56'14.46" and a longitude of 78°9'5.22".

2.3 Loads Acting on Silos

Silos are subjected to several types of actions or loads. As per Indian Standard Code, IS: 875: 1987 Part I-V, the following list of loads are to be taken for silo:

- Dead load (Self weight)
- Storage load (Material load)
- Live load (Platform area, Roof and Floor load)
- Wind load
- Imposed loads and deformation load

The following load combinations were taken into consideration.

LOAD COMBINATIONS – Serviceability Limit States

- D.L + 1.0 S.L (Filling / Empty)
- D.L + 1.0 S.L + 1.0 L.L (Filling / Empty)
- D.L + 1.0 S.L + 1.0 W.LX (Filling / Empty)
- D.L + 1.0 S.L + 1.0 W.LZ (Filling / Empty)
- D.L + 1.0 S.L +0.8 L.L+ 0.8 W.LX (Filling / Empty)
- D.L + 1.0 S.L +0.8 L.L+ 0.8 W.LZ (Filling / Empty)

2.4 Analysis

This section deals with the structural analysis of the various components of a silo during two stages, namely during the filling and emptying stages. This section further goes on to calculate the forces and thrust that are acting on each component such as the ring beam, the cone and the walls. The summation of the forces is done and the total moment is calculated. This moment is then used for the design of the silo.

The silo is designed for a capacity of 5000 tones and for a volume of 3205.128 m^3

Height = 21 m

The total height of the silo that will be used for the storage of material is 21 m.

The storage volume of the silo is 3231.06 m^3

The total storage volume of the silo structure represents the storage capacity of the structure. Since the total storage height is about 21 m, the volume is limited to that height of the structure.

The volume of the internal cone has been calculated and reduced from the total volume.

$$\varphi(z) = (1 - e^{-z/z0})$$

$$z_0 = 0.432$$

Using these given formulas mentioned as per the code, the various forces are calculated such as, Vertical Pressure, Horizontal Pressure, Tension and Wall Friction. These are calculated and tabulated below in Table-1. The values that have been obtained are further used in the design of the various components.

Table-1: Pressure Analysis during Filling Activity

z (m)	**P_{vf} (kN/m^2)**	**P_{hf} (kN/m^2)**	**T_{hf} (kN/m)**	**W_{ff} (kN/m)**
0	0	0	0	0
3	49.12	24.56	67.54	17.7
6	89.28	44.813	123.236	64.308
9	123.02	61.5122	169.158	136.414
12	150.56	75.28	207.02	229.027
15	173.27	86.63	238.248	338.55
18	191.99	95.99	263.99	462.01
21	207.43	103.717	285.22	596.97

The volume of the internal conical portion is 102.573 m^3

The total volume of the silo is 5077.38 m^3

As per Indian Standard IS 875 1987 Part III

Basic wind speed (Vb) = 50m/s

Design wind speed (Vz) = $V_b \times k_1 \times k_2 \times k_3$

Where,

V_z = design wind speed at height z
k_1 = probability factor (risk coefficient)
k_2 = terrain, height and structure size factor
k_3 = topography factor
k_1 = 1.0 (From clause 5.3.1 IS: 875: 1987)
k_2 = 1.1 (From clause 5.3.2 IS: 875: 1987)
k_3 = 1.0 (From clause 5.3.3 IS: 875: 1987)

Design wind speed (V_z) = 49.35 m/s
Design wind pressure = 1.5 kN/m²
Internal Diameter = 14 m
Internal Radius = 7 m
Area (A) = 153.86 m^2
Perimeter (U) = 43.96 m
Thickness (t) = 0.2 m
Height (h) = 21 m
Angle of Inclination (α) = 57.5
Density of cement (ϒ) = 18 kN/ m^2
Ratio = 3.5

From IS: 4995-Part 2, various pressures during the filling stage has been calculated by the formulas given below

Pressure on the wall due to friction

$$P_{wf}(z) = \frac{\Upsilon A}{U\varphi(z)}$$

From the above Table we can deduce that during the filling condition the highest force calculated is that of the wall friction which goes to show that during filling there will be more pressure that is applied on the walls.

The next condition taken into consideration is that of emptying. The values of which have been calculated and tabulated as per Table-2.

And from the two tables, it can be concluded that vertical pressure is higher during filling and horizontal pressure during emptying.

Table-2: Pressure Analysis During Emptying Activity

z (m)	**P_{ve} (kN/m^2)**	**P_{he} (kN/m^2)**	**T_{he} (kN/m)**	**W_{fe} (kN/m)**
0	0	0	0	0
3	44.64	44.64	122.76	32.75
6	75.04	75.04	206.38	115.33
9	95.75	95.75	263.33	231.84

12	109.86	109.86	302.132	371.46
15	119.47	119.47	328.55	526.83
18	126	126	346.55	692.93
21	130	130	358.813	866.32

From the above two tables, we can infer that the vertical pressure is higher during filling and horizontal pressure is higher during emptying .

$$\frac{h}{d} = 1.5$$

$2.5\ \mu = 1.125 < h/d$
Hence safe

2.4.1 Pressure on Silo Bottom

The pressure acting on the bottom of the silo by the stored material is calculated as follows by assuming that the pressure is uniform.

$$\frac{h}{d} = 1.5\ kN/m^2$$

Pressure is uniform

2.4.2 Hopper Load

Though the silo is designed to be an inverted cone silo, load on the hopper has to be calculated as shown below.

$$P_h = 149.42\ kN/m^2$$

On the vertical face (α = 90)

$$P_h = 225\ kN/m^2$$

2.4.3 Hopper Overfill

The pressure calculated in this section shows the pressure acting on the hopper when it in overfill state, or when the silo is in discharge mode.

$$P_{no} = 0.77104 \times P_{vf} + 1.0109 \times P_{hf}$$

$$P_{nu} = 0.433 \times P_{vf}$$

2.4.4 Switch Pressure

The pressure that acts at the junction of the two compartments is referred to as the switch pressure and is calculated as shown below.

Ps = 291.6 kN/m^2
bs = 4.2 m

The total force applied over the width
= 2450 kN/m

The switch pressure is applied above the cone but an equal and opposite reaction must occur on the ring
= 34300 kN
At z = 15 m

Pressure at the top of the cone
P_{no} = 133.598 kN/m^2

Pressure at the bottom of the cone
P_{nu} = 75 kN/m^2
Hoop Stress = 936 kN/m^2

For the calculated value
P_{no} = 133.598kN/m^2 C = 157.64 kN/m^2 p = 150.96 kN/m^2
P_{nu} = 75 kN/m^2 C = 88.5 kN/m^2 p = 85.275 kN/m^2

For a cone the ring compression force
= 619.5 kN/ m^2

This gives a stress of 1.82 (619.5/340) on the cone where 340mm is the thickness of the cone.

The length of the cone has been calculated below taking the internal angle as 57.5 which will give the inclined length of the conical part.

Length of the cone = 12.05 m
Pressure Gradient = 5.45
P = 150.96 – 5.45h
Circumference = 4h

The internal cone is split along its length that is of 12.05 m. It is divided into 8 parts each part 1.5 m in length, and the value of total thrust is computed at various heights and is tabulated and is shown below. The total thrust is the summation of all the thrusts at each height. From the value of total thrust that has been obtained, further computations have been made in Table-3.

Table-3: Computation of Total Thrust

h (m)	**P (kN/m^2)**	**Circumference (m)**	**Thrust (kN)**
1.5	142.78	6	1285
3	134.61	12	2433
4.5	126.43	18	3414
6	118.26	24	4257
7.5	110.175	30	4958
9	101.91	36	5503
10.5	93.74	42	5906

12	85.56	48	6160
Total thrust =33, 906 kN			

Ring Pressure = 771.3 kN/m
Tension = 5399 kN

2.5 Design

This section deals with the manual and software design of the various components of the silo such as the main walls, the compartment walls, the internal cone, the raft foundation. These components are designed to withstand the pressures and forces acting on the silo by the material during filling and discharge. The values from the analysis are used for the design procedure. This section also includes the reinforcement details of all the components.

Diameter (d) = 14 m
Ring tension = 5399.1 kN/m^2

Area of reinforcement = 15. 30 m^2
Perimeter (outer) = 45.216 m
Assuming 12mm dia bars
No. Of bars = 4 bars

2.5.1 Vertical Reinforcement

Wall is always subjected to compressive forces due to self-weight and wall friction. These reinforcements are provided to resist the axial loads that are acting on the structure.

Friction = 866.32 kN/m
Wall Self Weight = 216 kN
Ultimate Load = 1307. 32 kN/ m
Ac = 124.84 kN

The nominal reinforcement required for a silo is 0.2% as per IS 4995 part 2

As = 600 mm^2/m

Assume a reinforcement of 12 mm dia
No of bars = 5.3 or 6 bars
Spacing = 188.4 or 190 mm c/c

2.5.2 Design of Cone

The cone experiences compressive loads in both directions. Considering the cone as a wall. The cone is designed to resist the pressures by the stored materials on the cone during the process of discharge.

Capacity = 2720 kN/m
Ring Compression Pressure = 150.96 kN/m^2
Thrust = 33906 kN
Ring Pressure = 1156.9 kN/m^2
As = 680 mm^2/ m
No. of bars = 7 bars
Spacing = 166 mm c/c
Ast provided = 791.28 mm^2
Hence okay

The reinforcement details of the different components of the silo such as the external walls, wall below the cone and conical region have been shown below. The figure clearly depicts the positioning of the reinforcement bars in such a manner to resist the later horizontal pressures and make the structure more stable as one of the main reasons for silo failure is due to lack of careful calculation of lateral pressures acting on the silo hence optimising safety of the structure. The Fig-3, depicts a sectional view of the silo which shows the reinforcement details of the conical structure, ring beam and vertical reinforcement details of the wall

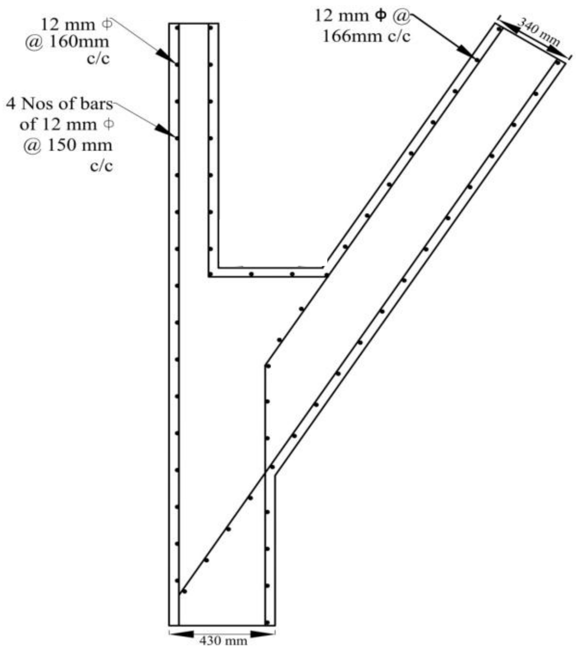

Fig-3: Reinforcement Detailing of the Sectional View

2.5.3 Ring Beam

Ring beam is provided in the structure to resist the various lateral pressures that act due to the movement of the stored materials. The main function of the ring beam is to resist hoop stress. The tensile thrust in the ring beam results from the cone thrust.

Total thrust = 356013 kN
Ring tension = 56690 kN
Area of reinforcement required = 160.708 mm^2
Assume 10mm diameter bars
No of bars = 4 bars
Spacing = 300 mm c/c
Ast provided = 314 mm^2

2.5.4 Check on Design of Wall

A manual check has been performed on the design of wall as shown below to ensure that the stress values obtained are within permissible limits.

Maximum vertical load on the wall(N) = 112.43 kN/m^2

Eccentricity (e) = 115 mm

$$\frac{P}{bh} = 2.61$$

Moment = 129 kNm/m

Provide 12mm dia bars @ 150 mm c/c
Ast% = 0.18 %
Mcap = 130 kNm/m
= 130 > 129
Hence it is okay
Reaction for live load = 207.43 kN/m
e = 0.43
M = 89.19 kNm/m

This moment is resisted by both the side walls and the cone.
Wall above = 105 kN/m
Moment = 12.07 kNm/m
Mcap = 46.24 kNm/m
Total Rotational Capacity = 188.31 kNm/m
= 188.31 > 89.19 kNm/m
Hence safe

2.6 Column Design

The columns in the silo are designed to withstand the transfer of loads from the top of the structure which can be calculated manually..

Pu = 1135 kN/m
Self-Weight = 17.5
D = 500 mm
L = 3500 mm
fck = 40 N/mm^2
fy = 415 N/mm^2

Pu = 1135 kN
Factored Pu = 1703 kN
Slenderness Ratio (L/D) = 7 < 12
(Therefore it is a short column)

Minimum Eccentricity (e_{min}) = 17 mm < 20mm
Also 0.05D = 15 mm < 20 mm
Hence safe as per IS: 456

2.6.1 Longitudinal Reinforcements

As per IS: 456 clause 39.4, longitudinal reinforcements in columns have been calculated as shown below.
Asc = 1875.8 mm^2
Min Asc = 565 mm^2
Hence okay

Provide 20 mm dia bars
No of bars = 6 no of bars
Spacing = 167 mm c/c
Ast provided = 1884 mm^2
Hence okay
Provide 6 no of 20 mm dia bars @ 167 mm c/c

2.6.2 Helical Reinforcements

Since the columns provided are circular columns, helical reinforcements are provided through the length of the column. Assuming a clear cover of 40 mm over spirals

Core diameter = 220 mm
Area of core = 36110 mm^2
Volume of core/m = 36110 × 10^3
As = 4521.6 mm^2

Provide 8 bars of 28 mm diameter
Ast provided = 4923.52 mm^2
Hence it is safe

The column reinforcement details have been shown in the fig below. The Fig-4 comprises of both a plan and a sectional view of the columns and also shows the various types of reinforcements, namely helical and longitudinal that are designed for each column in the silo.

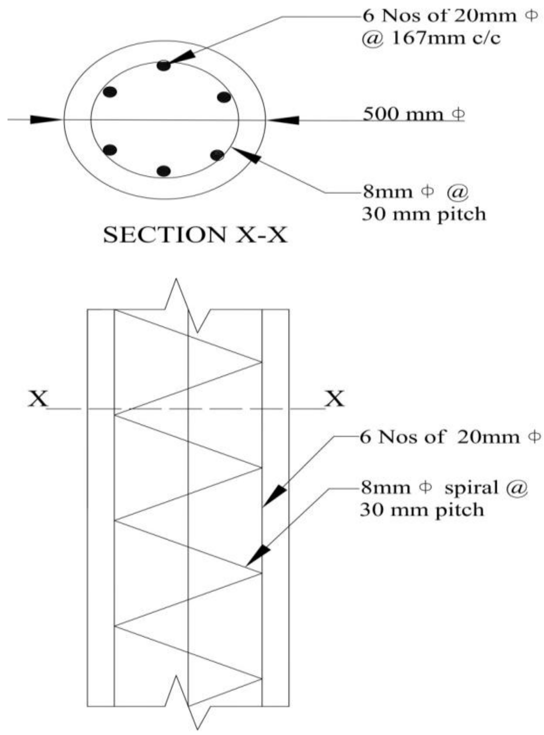

Fig-4: Reinforcement Details of Column

2.7 Design of Mat Foundation

The foundation adopted is that of raft foundation or commonly known as mat foundation, this foundation is so adopted to avoid differential settlement in soil, as the soil type (stiff clayey soil) is more prone to differential settlements. The load transfer to the foundation takes place through a circular beam placed to ensure easier load transfer onto the ground.
Total load = 22473 kN
SBC = 100 kN/m^2
Area of raft = 225 m^2
Length = 15 m
Breadth = 15 m
Depth (d) = 1032.6 mm

Overall depth = 1070 mm
As = 12178 mm^2/m
Provide 16mm diameter
No. of bars = 62 bars
Spacing = 250 mmc/c
Ast provided = 12459.52 mm^2/m
Provide 16mm diameter at 250mmc/c both ways.

2.7.1 Design of continuous beam over raft slab

The raft slab has been provided with a continuous slab over it for the ease of load transfer from the silo structure.
d = 400 mm
Overall depth = 450 mm
As = 1081.2 mm^2/m

Provide 25 mm diameter 4 bars both at top and bottom to resist negative moment
Ast = 1963 mm^2

2.7.2 Shear Reinforcement

This reinforcement has been provided to resist the shear forces acting on the structure. These reinforcements in turn increase the stability of the silo to a large extent.
As = 1.635
Using 10mm diameter 4 legged stirrups
Spacing = 195 mm or 200 mm

The above Fig-5 shows the reinforcement details of the raft slab or the type of foundation that has been adopted. The details of the circular beam that is placed all throughout the mat foundation for the easier transfer of loads is also shown.

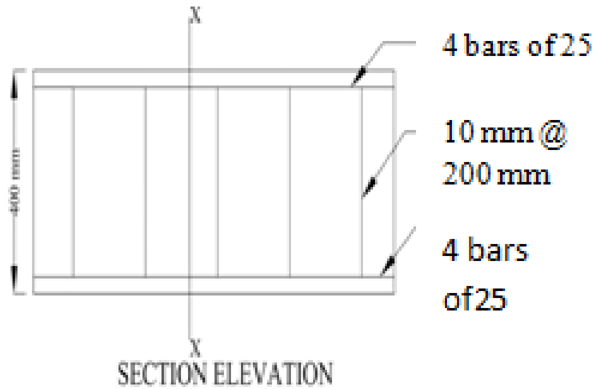

Fig-6: (a) Sectional Elevation of Continuous Circular Beam over Raft Slab

3. CONCLUSION

Since silos are in growing demand with the fast progressing cement industry. These structures, though in much demand have a high rate of failure all through the world.

- Considering the safety constraints, compartmental walls and a central cone was included in the design, after which a uniformity in stress distribution was observed. This further prevented the concentration of stress on any one particular area on the silo, which is one of the leading causes of silo failure.
- The range of the stresses experienced by the members of the structure were from -1.59 N/mm^2 to about -0.181 N/mm^2 which is well within the safe permissible limits of allowable stress as per the Indian codal requirements.
- The structural members of the silo are subjected to a maximum deflection of 0.023 mm which further reinforces the safety of the structure.
- To make the structure economic the design of the various components was done after proper analysis taking into account various pressure and moment values which were adopted from the analysis part of the silo.
- Each component was designed for a minimum area of steel hence making it economical and safe. Reinforcements were also provided according to the need and requirement of each component. Hence it is seen by the inclusion of two major components into the design of a conventional silo, namely multi compartment walls and the internal cone, the safety of the structure can be optimized and high rates of failure avoided.

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