DESIGN OF LARGE SIZE SILO

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CERTIFICATE

This is to certify that the dissertation report entitled **"DESIGN OF LARGE SIZE SILO"** submitted by **Mr. Alpeshkumar Popatlal Patel (02MCL07)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Engineering (CIVIL)** in field of **Computer Aided Structural Analysis And Design** of Gujarat University is the record of work carried out by him under my supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for examination. The results embodied in this dissertation, to the best of my knowledge have not been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Looking to the fast pace of development that is to be taken care of by professional engineers and globalization of professional services to be rendered, it becomes important to appraise them in the area of design for industrial structures, which has a wide spectrum to be dealt with.

Bunker and silo is one of the storage structure required for industrial plants to store various kinds of materials such as coal, grains, cement etc. Hence it is necessary to appraise regarding the design procedures for such structures, which includes the study of codal provisions leading to analysis and design along with detailing of the same.

The present study is the step in the direction to give relevant technical information, illustrating the theoretical background and codal provisions along with detail design procedure and use of computer programming language (c++) for analysis and design of various components of silo.

CHAPTER 1.Covers abstract and conclusion of each write up presented in various research papers, books, journals, websites etc. which focus on various aspect of structure like behavior of structure after construction, different shape of container and effect of it on silo wall analysis, comparison of software result with manual calculations for analysis of inverted cone, stresses in silo and a case study on tower silo foundation. It also includes several experimental studies on silo, which gives brief knowledge of behavior of silo.

CHAPTER 2.Deals with theoretical background of analysis and design of various components of silo. It includes introduction, classification and definition, functional design of bin, different flow pattern, and methods due to granular and powdery material. It also includes effect of opening, flow irregularities etc.

CHAPTER 3.Covers load consideration in silo design, which includes different loads like dead load, live load, equipment load, wind load, load due to thermal effect, seismic load and combination of loads.

CHAPTER 4.Deals with design aspect of R.C.C silo, provision of reinforcement as per Indian code and ACI code, theoretical aspect of special silo like ring silo, homogenizing silo, FRP silo, prestress concrete silo. It also includes construction methodology for silo and parametric study on effect of opening.

CHAPTER 5.Explains the design example in which calculation of analysis and design of each component of double cylindrical concentric silo (ring silo) has been explained. Analysis of inverted cone is done using STAAD-PRO software.

CHAPTER 6.Conclusions from the study and future scope is covered in this chapter.

Computer programming of different components of silo are listed in Appendix-I. Comparison of results obtained from manual calculation and from programming is tabulated as shown in Appendix-II. Detailed drawings are given in Appendix- III.

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FIGURE INDEX

.

TABLE INDEX

NOMENCLATURE

D	=	Diameter of silo
H	=	Height of silo
D_o	=	Diameter of outer silo
D_i	=	Diameter of inner silo
ϕ	=	Angle of Internal friction
Mr	=	Maximum radial moment
M_θ	=	Maximum circumferential moment
Lo	=	Anchorage length
Ld	=	Development length
R	=	Hydraulic radius
w	=	Density of cement
μ_f	=	Angle of wall friction while filling
μ_e	=	Angle of wall friction while Emptying
p_h	=	Horizontal pressure on silo Wall
P_w	=	Frictional load on wall
λ_f	=	Pressure ratio during filling
λ_e	=	Pressure ratio during emptying
Zo_f	=	Depth During filling
Zo_e	=	Depth During emptying
δ	=	Angle of wall friction
C_d	=	Over pressure factor
μ'	=	Coefficient of friction between cement particles and concrete wall
t_{min}	=	Minimum thickness of the wall
η	=	Concrete shrinkage coefficient
Es	=	Modular of elasticity of reinforcing steel
σ_{sa}	=	Stresses in reinforcing steel
m	=	Modular ratio
σ_t'	=	Tensile strength of concrete
Ty_{st}	=	Static ring tensile force per unit length of wall
t	=	Wall thickness
β	=	A coefficient depending upon the soil- foundation system
I	=	A factor depending upon the importance of the structure
α_0	=	Basic horizontal seismic coefficient depending on the different zones
σ_{cr}	=	Allowable buckling compressive stress
e_x	=	Eccentricity about x-x axis
e_y	=	Eccentricity about y-y axis

CHAPTER 1. LITERATURE REVIEW

1.1 DESIGN OF STORAGE FOR STORING GRANULAR MATERIALS by Falguni Basu

Source: Indian Concrete Journal Vol. 75

ABSTRACT

Silos are the structure for storing granular and powdery materials. In this paper, the author presents a new approach, which takes care of dynamic stresses while emptying and impact stresses while filling. Janssen's method has been used in the static storage case.

A silo is a container circular or polygonal in plan. Usually circular silos are preferred. Granular material are those such as sheet, paddy, rice, corn, etc whose mean particle size of more than 0.2 mm. silos are used for storing powdery material such as cement, flour etc. whose mean particle size is less than 0.06mm. In this paper, the design of a single silo is considered.

The analysis is made for three cases as follows:

Case 1. Filling from the top, bottom gate closed
Case 2. Static storage condition, when silo is full and bottom gate closed
Case 3. Emptying from the bottom by opening the gate

Though the IS 4995 recommends the consideration of only cases 1 and 3 for obtaining the pressure distribution inside, it has been found to be wrong to use Janssen's formulae as dynamic stresses are set up inside. As a result, many silos were damaged. Anti dynamic devices were installed to take care of the excess pressure while discharging during repair of the damages.

Case 1. Filling from the top

In this case, the vertical pressure will be maximum when the conical section or hopper is full and circular section is being filled.

Case 2. Static condition when the silo is full

In this case, since the granular material is at rest we shall use Janssen's theory for the calculation of horizontal and vertical pressure.

Case 3. Emptying from the bottom

Dynamic stresses are set up in silo wall in this case. Since there is sliding of material, arching takes place transferring a large part of the fill weight to the silo wall. It is possible to determine the distribution of normal stresses on the surface of the sliding by Kotter's equation.

CONCLUSION

From above study, it is seen that the horizontal pressure distribution is maximum for all depths in case3 Emptying condition but vertical pressure for case1 filling condition gives maximum value. These findings are not in agreement with provision of IS 4995

1.2 STUDY OF HORIZONTAL PRESSURE ON WALL OF CIRCULAR AND VRATTAYATA SHAPE SILOS by L.M. Gupta and N.V. Despande

Source: Indian Concrete Journal Vol.77.

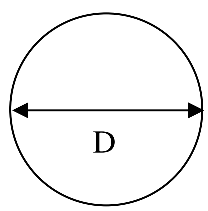
ABSTRACT

The text deals with Janssen's theory for computing horizontal pressure exerted on silo wall due to stored material at rest. The computation of pressure at various elevation of the wall is made for Circular and Vrattayata shape silos. The dimension of this silo is so selected such that they have the same cubical content. The curve have been plotted to study the effect of hydraulic radius on the horizontal pressure at certain depths.

Geometrical properties of silo shapes:

Circular silo having diameter of 12m and height of 30m is selected for the study

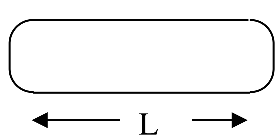
$A = 0.25\ \pi \times D \times D$
$P = \pi \times D$
$R = 0.25\ D$
$V = A \times H$



Vrattayata silo:

The 5m, 5.5m, 6m radius of semicircular portion for Vrattayata silo is considered with varying straight length. Five combinations are studied for each of the radius. The volume content in each silo kept same as that of circular silo.

$L = 2 \times X \times R$
$A = (\pi + 4 \times X) \times R \times R$
$V = A \times H$



The study has been made for the effect of hydraulic radius on horizontal pressure when the material is at rest. For this, the depth of 12m, 21m, 24m, and 27m has been selected.

CONCLUSION

For study of horizontal pressure vs. depth

1. For all chosen dimension of Vrattayata silos, at rest the horizontal pressure is more than that of circular silo at the same depth.
2. The observed change in pressure is more at the depth of more than 18m
3. Even though the horizontal pressures at various depths are calculated using exponential relationship, in some of the cases the curve between the depth v/s pressure fits more accurately into the 4^{th} degree polynomial relationship.

1.3 STRESSES IN SILOS by Dietmar Schulze

Source: **www.dietmar-schulze.de**

ABSTRACT

Knowledge of the stresses acting in silos is important for many applications:

- Silo design for strength (e.g. DIN 1055 part 6 [1])
- Silo design for flow
- Loads on feeders and inserts
- Driving torque of feeders
- Design of silos in which a specific maximum stress is not exceeded (e.g. to avoid vibrations, particle attrition or extreme time consolidation)

The calculation methods used by an engineer, who is interested in avoiding flow problems in feeder design, differ from the calculation methods of a civil engineer (e.g. DIN 1055 part 6 [1]) who is interested in the stability of the silo structure. The civil engineer would choose the parameters for calculating silo stresses so that the major part of the load from the bulk solid is carried by the silo walls, whereas the engineer who has to calculate the feeder load and the required driving power would assume that the silo walls carry only a minor part of the load of the bulk solid. The stress distribution across the periphery of the silo is another example of the different points of view, whereas a strong irregular distribution of the stresses on the silo wall is quite unimportant for the design of a feeder, these different stresses cannot be neglected for the structural design of the silo walls.

For the stress calculation, a bulk solid is considered as continuum instead of single particles. Because of this the methods of continuum mechanics can be applied. If different sloped cuts through an element of bulk solid are considered it can be seen that different shear and normal stresses are acting at different cutting planes. This is shown in

a simplified way where the stresses σ_h and σ_v, which act in different directions, differ from each other. In a bulk solid there is one direction where the maximum normal stress is acting. This maximum normal stress is called major principal stress σ_1. The minimum normal stress which acts perpendicular to σ_1 is called minor principal stress σ_2.

CONCLUSION

In contrast to a fluid, a bulk solid at rest can transmit shear stresses. While the pressure in a container filled with a fluid increases linearly with the depth Figure 1.3(a), the weight of the bulk solid in a silo is carried partly by the silo walls because of the shear stresses (friction at the silo wall) so that the stress does not increase linearly with the depth like the pressure of a fluid.

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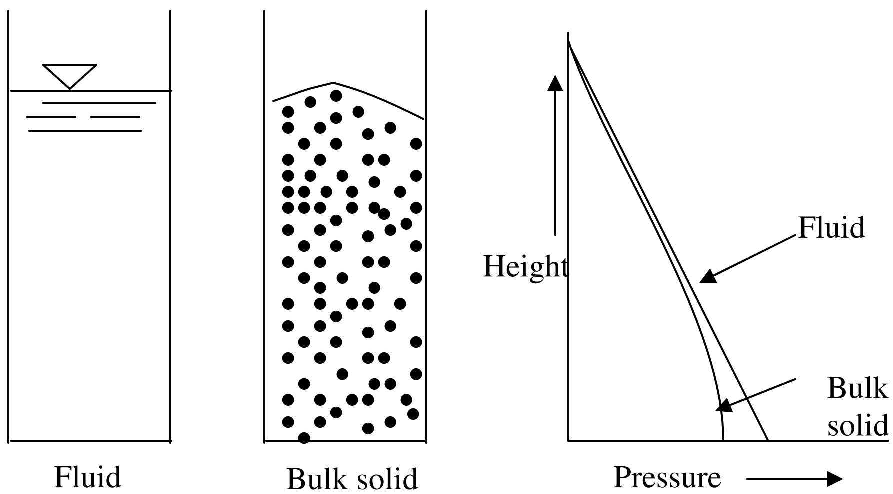


Fig. 1.3 (a): Pressures in fluids and stresses in bulk solids (in principle)

1.4 TOWER SILO FOUNDATIONS by M. Bozozuk

Source: www.dietmar-schulze.de

ABSTRACT

Tower silos, tall, bullet-shaped farm structures, are used to store forage crops for feeding cattle. The first tower silos, constructed about 40 years ago, were small, predominantly wooden structures although a few were made of concrete. Since then they have increased in number, size, and capacity, most made of concrete but some of steel. In 1974 more than 3,000 tower silos were erected in Ontario and Quebec, representing an investment of over $30 million by the agricultural industry in these provinces alone. Some recent structures are fully automated exceed 100 ft (31 m) in height, and have a storage capacity of more than 2500 tons.

Over the years silo builders have improved the design and construction of the above ground portion of silos but, in contrast, very little has been done to improve the foundation. Towers have generally been erected on foundations prepared by the farmer, who often lacked the necessary technology for adequate design and construction. The practice was reasonably successful when silos were small because the bearing pressures applied to the soils were low. As bigger silos were erected, however, and the applied foundation pressures approached the bearing capacity of the soils, many structures settled considerably, some tilted, and some overturned completely. This Digest outlines the problem and indicates the need for a soil investigation to determine the allowable bearing capacity and compressibility of the soil and thus enable proper foundation design.

Many tower silos constructed on clay soils have ring-shaped concrete foundations. When
the silos … walls to the
footings a… …ndation. The
underlyin… …h a way that
the applie… …losed by the
circular f…

Non-unif… …s. When the
load fron… …distorted, as
shown in… …same effect.
The local… …e problem is
remedied…

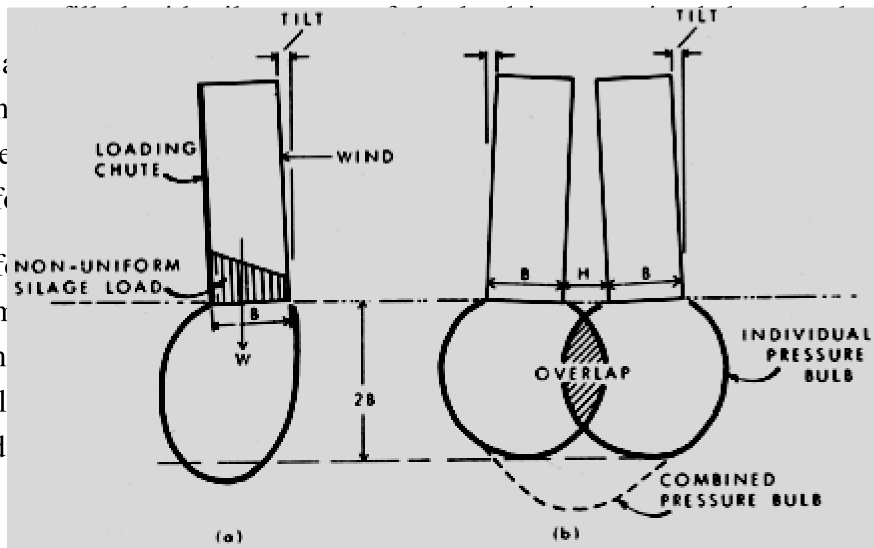


Fig. 1.4. (a),(b) Non-uniform and overlapping pressure bulbs.

Pr … os are
co … ressure
bu … p zone
wi … more,
ca …

Fig.1.4(c). Leaning twin silos caused by non-uniform settlement in zone of overlapping pressure bulbs.

CONCLUDING REMARKS

The agricultural industry should be aware of the many aspects of design and construction of tower silos on clay soils. A contractor's experience may be sufficient for building average size structures, but for very large tower silos there should be a thorough soil investigation carried out under professional guidance. It is not possible to build an economical and safe foundation unless the properties of the foundation soils are known and considered in the design. Furthermore, quality control and on-site inspection is required during construction.

Performance requirements for tower silos also have to be established. For example, how much vertical settlement or tilting can be allowed without the performance of the structure being affected? Is there an optimum limit for the ratio of height to diameter of the silo? Answers to these and other questions can be obtained by studying the performance of existing silos and from the instrumentation of new structures on different soils.

1.5 FINITE ELEMENT ANALYSIS OF INVERTED CONE FOR 20,000T. CAPACITY CEMENT SILO - A CASE STUDY By A.K. Samanta

Source: Journal of institution of engineers, Vol 77.

ABSTRACT

The capacity of analyzing complex structures to a great extent is possible now a day with the introduction of advanced numerical methods like finite element analysis and that of modern computer software like STAAD-Pro. In this paper, the author has compared the result of software/ FEM analysis with those calculated following standard formulae.

In this case it is a 20,000t R.C.C cement silo with inverted right circular cone having a ring beam at the base of the cone. In static condition the cone carries material pressure along with its self-weight. As a result meridional and tangential stresses developed in the cone shell, which are usually compressive in nature. The inverted cone has been modeled in STAAD-Pro with hinge support at the column locations for the simplicity of analysis. The entire vertical height of the cone has been divided into 13 equal divisions and the perimeter has been divided into 48 equal divisions. The external load has been calculated at each node using the standard formulae and than loads are applied as a nodal loads. In the second method, analysis of inverted cone is done using standard formulae of Safarian and Harris and the shell stresses at the base level are calculated. Result of both methods is compared and final conclusion is made.

CONCLUSION

The proper modeling of a problem, where actual support condition is configured, can only depict the true nature of deformation as well stress variation. Since the base of the inverted cone is supported on a number of columns having very less area of cross section, the column cannot restrict the possible extension of the ring at the openings. Also the column cannot resist the rotation at the supporting joints and as a result, the part of the periphery at the same level between the supporting columns is subjected to considerable deformation. The results by standard formulae have been obtained considering the base continuously supported at the base and also the design stresses are much on conservative side which requires almost 25% higher reinforcement than that following FEM analysis. In this case the deformation pattern is also not transparent to the designer. So FEM is much better tool to understand its behavior depending on the height to base diameter ratio, non- uniform loading pattern provided a proper supporting condition is simulated.

1.6 EXPERIMENTAL STUDIES

1.6.1 HISTORICAL BACK GROUND

M.S Ketchom describes numerous early experiments conducted in Europe and the United States, including his own tests. These early experiments on small-scale models and actual full size silos employ intensive pressure measuring devices. Several experiment coupled with improved analytical studies, have provided a better understanding of the behavior of stored granular material in motion. Also it has become apparent that Janssen's and Airy's solution s may not be entirely accurate even for material at rest and that lateral pressure during unloading are much higher than those computed by either of these method.

Here several experimental works, which are summarized in, approximate chronological order. Details of selected experimental works are given below

1.6.1.1 TACHTAMISHEV'S WORK

He is one of the first researchers to conduct accurate experiment on full size industrial silo in Russia during 1993 to 1942. He reported that lateral pressures during emptying are 1.65 times to 1.35 times higher than static pressure.

- His experiments also classified the flow in two general classes which now are known as funnel flow and mass flow in these observations, he termed them as Non-dynamic flow respectively.
- He observed that mass flow (dynamic flow) produced considerably larger lateral pressures on the silo walls than the funnel flow.

1.6.1.2 MARCEL AND ANDRE REIMBERT EXPERIMENTS

Theoretical and experimental works by Reimbert were conducted between 1941 to 1943 on model bins of different forms sizes and heights in France.

- Apart from experimental work they have also developed their own theory for calculating pressures of granular materials at rest as well as in motion.
- Based on their experiments they observed that

1. The ratio k of lateral to vertical pressure is not constant but varies with height of the material and form of the silo.

2. For silos with same hydraulic radius and same depth the pressure is not same and varies with the form of silo.
3. In rectangular silos the average pressure is not the same on the short and long wall.

Comparison of two tests of same material on the same silo showed that over pressure factors are variable. They concluded that during emptying disturbances in the equilibrium of stored mass are such that it is not possible to estimate the behavior with sufficient accuracy or to express it mathematically.

1.6.1.3 PIEPER AND WENZEL'S EXPERIMENTS

These experiment were conducted in 1963 and become the basis for German silo code published in 1964. Their tests were carried out on model silo and following observation were recorded.

1. Maximum lateral pressure during emptying was 1.79 times of the pressure during filling.
2. Walls with smooth surfaces had higher lateral pressure than those with rough Surfaces.
3. Lateral pressures during simultaneous filling & emptying were comparable to the pressures during emptying.
4. Co- efficient k of Rankine's active condition (in Janssen's theory) is incorrect ($1-\sin\phi$ / $1+\sin\phi$) instead value of k is approximately same as earth pressure at rest.
5. Compared to the effect of emptying the roughness effect on angle of friction was found negligible.

Conclusion of study: Based on above study Pieper & Wenzel gave two separate equations for determining pressures in silos.

- One for calculating pressures during filling (giving large vertical pressures).
- The other for pressures during emptying (giving large lateral pressures)

1.6.1.4 SUGITA'S TESTS

Sugita's tests were conducted in early 1970 in Japan and are of interest to know about flow patterns. The test conducted on a flat-bottomed silo (primarily funnel flow) showed flow pattern, which is explained in stages by Sugita as follows-

Soon after the start of emptying the following zones spreads vertically above the emptying hole. At the steady state, material sank uniformly in zone F_1. Zone F_2 is one in which the arriving material is thrown into zone3 with radial velocity. In zone F_3, the material fell vertically and with a high velocity. Zone F4is a dead zone. The boundary between zones $F_1$and F_2 is collapse plane, where the material of F_1 reaches failure state and flows plastically.

1.6.2 SUMMERY OF EXPERIMENTS

Important conclusions of all these experiments are:

- There is no unique flow pattern even for a particular material in a particular silo. However basic flow patterns are mass flow and funnel flow.
- During operation of silo the pressures increase above static conditions.
- The result of experiments varies about the magnitude of increase and their distribution.

CHAPTER 2. STORAGE STRUCTURE: SILO

2.1 INTRODUCTION

Vessels of different shapes, size and material are needed for the storage of gaseous, liquid and solid products. The designer of storage structures has to deal with non-hazardous aqueous liquids such as water or volatile liquids such as gasoline. Storage of powdery material such as cement and sugar and granular material such as coal and wheat are other facets of the problem. The designer of storage structure must have links with petrochemical, food, agriculture, cement, mineral and pharmaceutical industries to supply the different structures suited to their needs.

Structure for the storage of solids is generally referred to by the name Bin. A bin is simply an upright container and the name includes shallow containers known as bunkers and tall structure known as silo. Steel bin usually rectangular or circular in cross section and are supported on column or skirts as shown in figure2.1.

Reinforced concrete bins usually rectangular but tall silos are cylindrical as shown in figure2.2. Normally 500 to 2000 tones of granular material is stored in a single bin and large quantities of the order of 10000 tones or more are to be stored, the material is divided into two or more bins forming a continuous nest or Battery as shown in fig 2.3. In this multi-bin configuration, even the intermediate bin forming the intestinal space and the pocket bin formed at the end are used for the storage. Prestressed concrete silos are also extensively used for the storage of cement, and clinker, alumina, sugar etc. For the storage of powdery material in plastic industry, fiber-reinforced plastic silos are used.

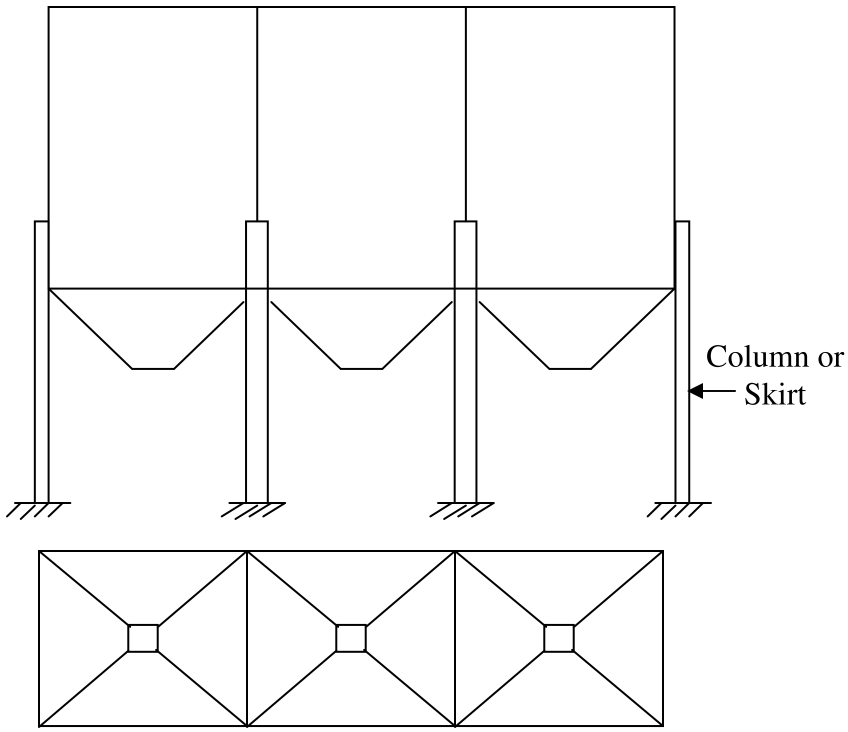


Fig. 2.1

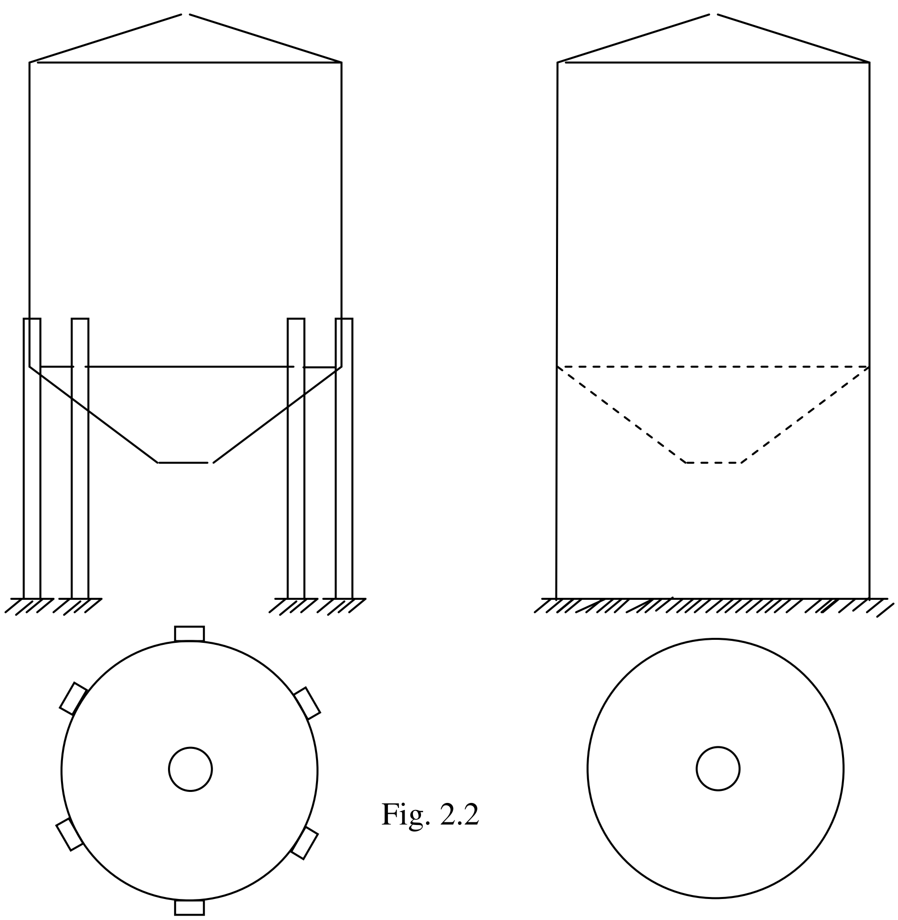


Fig. 2.2

Fig 2.1 and 2.2 General arrangement of bunker and silo

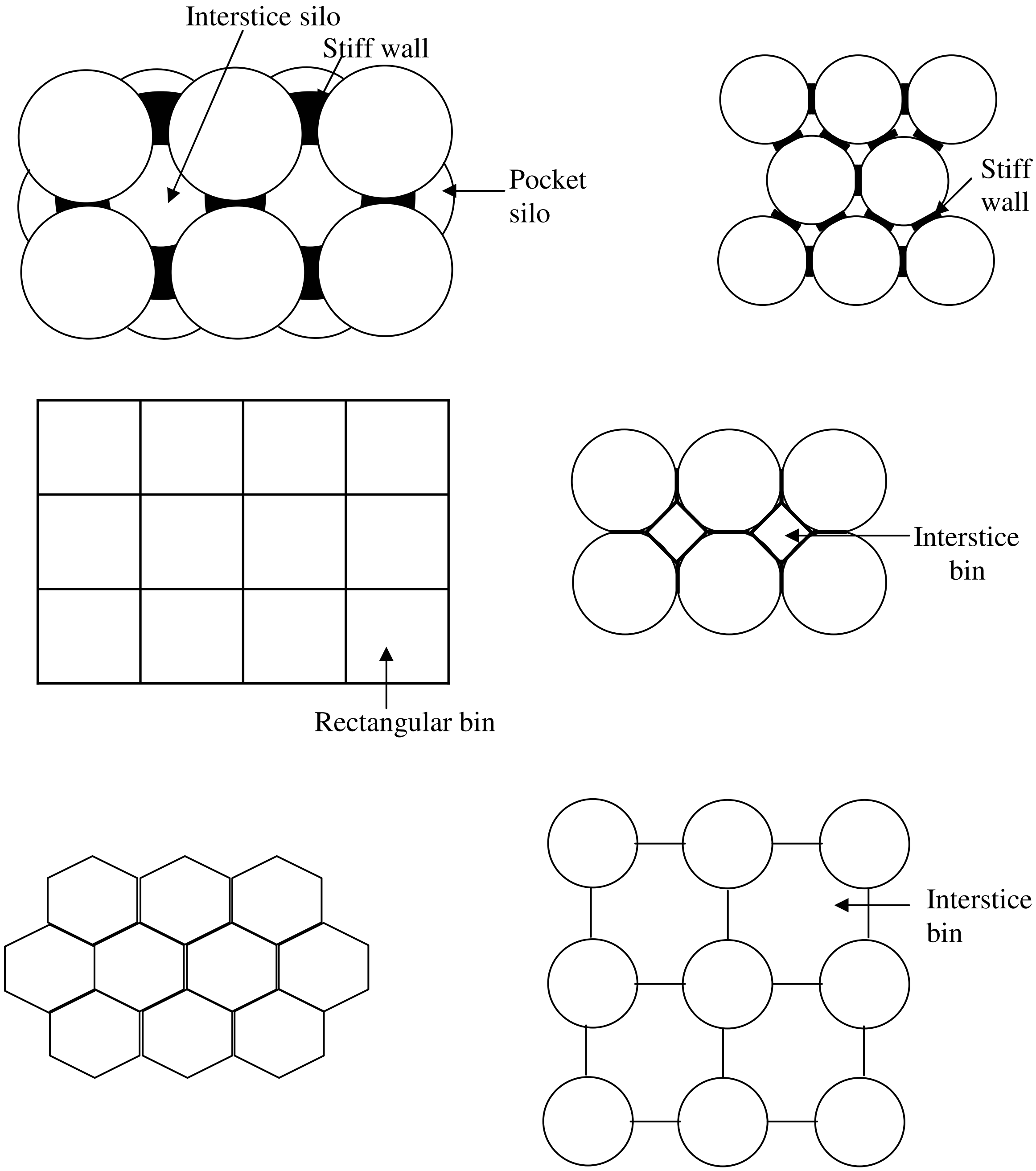


Fig. 2.3 Different Geometrical shapes of silos

2.2 CLASSIFICATION AND DEFINATION

The terms bin for silo and bunker have different meanings in different part of world and may vary from author to author. In the United State the term bin generally includes both silos and bunkers. Deep bins are silos and shallow bins are bunkers.

The propositions of a bin especially the ratio of material depth to least material dimension affect the behavior of stored material both at rest and during discharge. Assuming that bin geometry affects pressures, to select the proper basis for pressure computation the bin is classified either as a silo (deep bin) or a bunker (shallow bin). Accurate classification may soon be feasible but presently the following methods are widely used in practice:

(a) Empirical approximation – Practiced by engineers and also supplemented by Soviet code:

$H > 1.5\,A$ where A is diameter for circular bin and shorter length for rectangular or square bin

If storage structure in question satisfies above, it is consider as a silo or otherwise it is a bunker.

(b) An approximation based on the position of the plane of rupture:

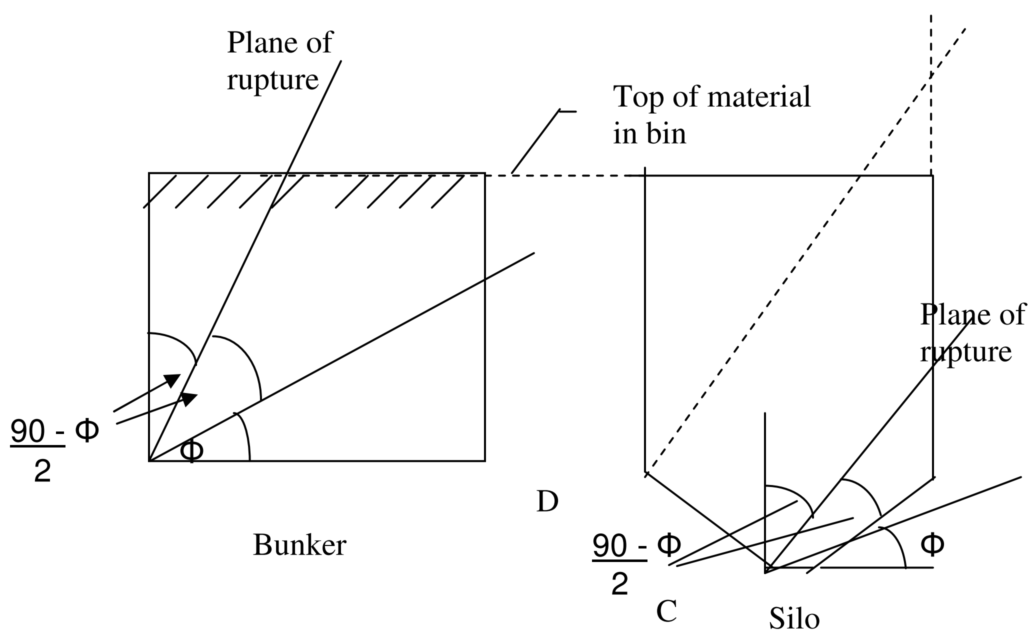


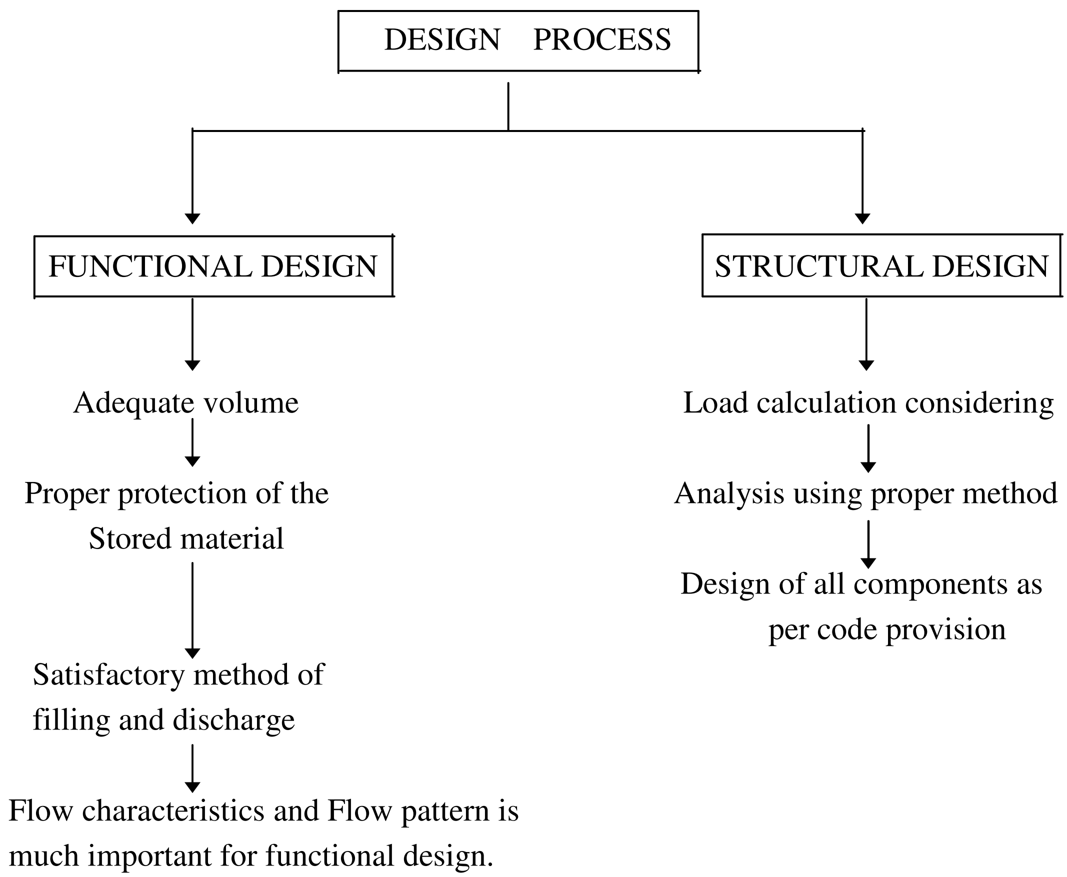
Fig 2.4

Figure 2.4 shows bins of two different depths. The plane of rupture is determined by the Coulomb theory. If the rupture plane intersects the top surface of the stored material, the bin is a bunker otherwise it is a silo.

However engineers do not agree on the location of the plane of rupture. Some would start the plane at the bottom of the hopper, point C of figure 2.4 while other would pass it through point D, at the bottom of the vertical wall. Thus by one interpretation the bin would be a silo; by the other a bunker. This is recognized by the ACI 313 standard, which for simplicity and without significant error allows all vertical containers, regardless of their height to depth ratio to be considered as silo. Therefore under ACI 313 method of pressure calculation for silo is also used for bunkers.

2.3 FUNCTIONAL DESIGN OF BINS

1. FUNCTIONAL DESIGN
2. STRUCTURAL DESIGN



2.4 CODES AND STANDARDS

To help ensure safety and better quality silo and bunker structures, several countries have already adopted codes and standards for silo and bunker design and construction. Few of them are as below:

I.S 4995- 1974: Criteria for design of reinforced concrete bins for the storage of granular and powdery materials.

Part 1. General requirements and assessment of bin loads.

Part 2. Design criteria

DIN 1055: "Design Loads for Buildings; Loads in Silos" Silo Code in Germany

CH 302: "Instruction for Design of Silos for Granular Materials" Silo code in the United States

ACI- 313: "Recommended Practice for Design and construction of concrete Bin" Silo code in the United States

2.4.1 COMPARISION OF ACI 313 (1991) AND I.S 4995 (1974)

The comparison given below covers only the points where difference exists between I S 4995 (1974) and ACI 313 (1991)

No.	As per IS 4995 –1974	As per ACI 313 – 1991
1.	WALL PRESSURES	
a.	Uses Janssen's formula but gives different factors for emptying and filling conditions.	Uses Janssen's formula and defines overpressure factor for emptying and other effects.
b.	Differentiate between granular and powdery materials for pressure calculation	No such difference on the basis of particle size of the stored material.
c.	Table in code gives for co- efficient of wall friction and pressure ratio during filling and emptying.	Co-efficient of wall friction and pressure ratio for all conditions depend upon angle of repose of the material.
d.	Method for calculating pressure due to eccentric discharge given.	Over pressure factor does not take care of eccentric discharge condition.
e.	Load reducing effect of bin bottom considers height up to 1.2 d or 0.75h which ever is less.	Load reducing effect is limited only within the height of hopper.
f.	For seismic loads, reference to IS 1893 – No other 'silo' specific recommendation.	For seismic load, 80% of the weight of the stored material only to be considered.

2.	DESIGN		
	a.	Permissible stresses for elements in contact with stored material are defined in silo code.	Design is as per code of practice for R.C.C design – ACI 318
	b.	Method defined for working out the minimum wall thickness to be provided.	Minimum wall thickness for all cast-in-place silos specified.
	c.	Different method to calculate effect of difference between ambient temperature & temperature of stored material.	Commentary gives method to calculate effect of temperature difference and considers that up to a difference of 44°C, there is no effect.
3.	DETAILING		
	a.	Note about openings larger than five times the wall thickness given- but no specific recommendation given.	Clear recommendations for all types of openings – in pressure zone as well as in non-pressure zone–given Length of extra reinforcement beyond the opening also defined.
	b.	No recommendations about taking horizontal reinforcement below pressure zone.	Specific recommendation about taking horizontal reinforcement at least six times the wall thickness below pressure zone.
	c.	Splice of horizontal reinforcement as per IS 456	Additional requirement of splices and minimum cover for horizontal reinforcement recommended in silo design.

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2.5 MATERIAL PRESSURE

2.5.1 METHODS DUE TO GRANULAR AND POWDERY MATERIAL IN SILO

Early silo designers not recognizing the importance of vertical friction between stored material and the silo wall, assumed lateral pressure to vary hydrostatically. This assumption often gives wasteful conservative results.

Subsequently analytical methods were developed that consider wall friction. These methods provide means for computing

(1) Pressure of the stored material against vertical walls, and flat bottom

(2) Friction forces and wall compression forces

(3) Vertical pressure at various depths in the stored material itself.

Some of these methods give static pressures only. During filling or emptying of the silo the pressure will be higher than static. These methods are based on equilibrium of the stored material in a static condition. Elastic interaction with the bin structure is not considered, nor is strain energy in either the stored material or the structure. These analytical methods correlate with test measurements with varying degree of agreement

2.5.1.1 JANSSEN METHOD FOR COMPUTING STATIC PRESSURE

This method is based on equilibrium of a thin horizontal layer of stored material as shown by figure 2.5 (a).

Equating the vertical forces to zero gives

$$qA + \gamma A dy = A\,[q + dy(dq/dy)] + \mu'\,p(U dy)$$

In which, q = static vertical pressure at depth Y

A = Area of horizontal c/s

U = Perimeter of horizontal c/s

p = Pressure of stored material at depth Y

Substituting kq for p and hydraulic radius R for A/U and rearranging the equation

$$dq/dy = \gamma - (\mu' k/R)q$$

The solution to this differential equation is the Janssen formula for vertical pressure at depth Y.

$$q = \gamma R/\mu' k\,[1 - e^{-(\mu' k y/R)}]$$

By introducing the ranking coefficient for active earth pressure-the ratio of horizontal pressure to vertical and finally the equation for horizontal pressure is

$$p = \gamma R/\mu'\,[1 - e^{-(\mu' k y/R)}]$$

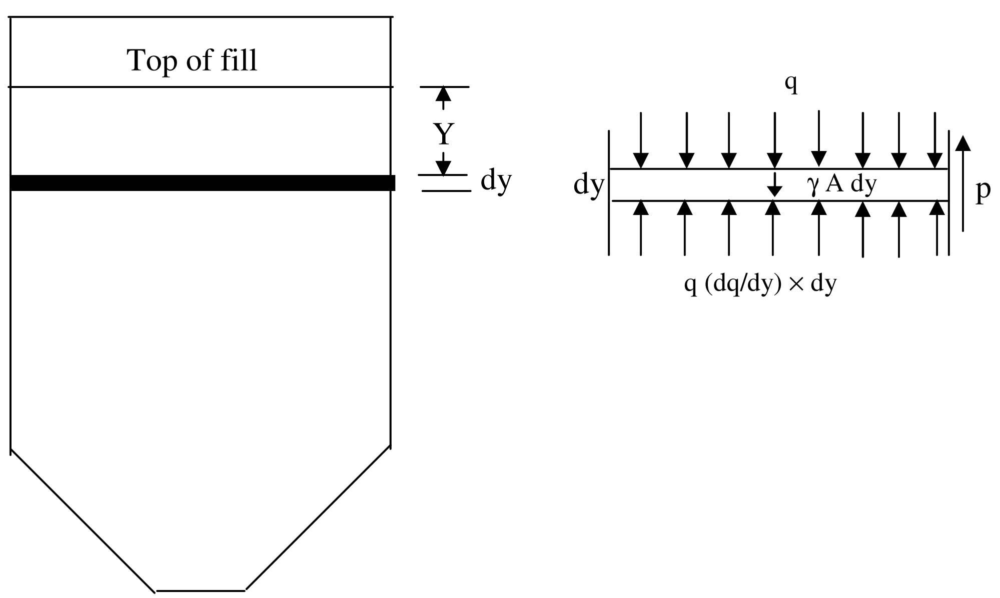


Fig. 2.5 (a) horizontal lamina for derivation of Janssen's formula

2.5.1.2 THE REIMBERT METHOD FOR COMPUTING STATIC PRESSURE

In 1953 and 1954 Marcel and Andre Reimbert presented their method for computing static pressure due to stored material. Their derivation shows that at larger depth Y the curve of lateral pressure becomes asymptotic to the vertical axis. At that depth the lateral pressure reaches maximum shown as $p_{max.}$ It has equal vertical pressure above and below.

$$\gamma A dy = \mu' \, p_{max} U dy$$

Thus

$$p_{max} = \gamma R/\mu'$$

in which, R = hydraulic radius = A/ U.

Vertical pressure at that location is:

$$q_{max} = p_{max} / k = \gamma R/(\mu' k)$$

The Reimbert equation for static pressure area as follows:

Vertical pressure at depth Y below stored material surface:

$$q = \gamma \, [Y \, ((Y/C)+1)^{-1}) + h/3 \,]$$

Lateral static pressure at depth Y:

$$p = p_{max} \, [1-(Y/C+1)^{-2}]$$

The terms in above equation are easily determined.
For circular silos the terms p_{max} and C (characteristic abscissa) in above equations are:

$$p_{max} = \gamma \, D/ \, (4 \, \mu')$$

$$C = D/ \, (4 \, \mu' k) - h/3$$

2.5.1.3 THE AIRY'S METHOD FOR COMPUTING STATIC PRESSURES

The method of Wilfred Airy presents separate solution for bunkers and silos. Airy's equation was derived considering static equilibrium of wedge shaped portion of stored material above the plane of rupture.

Figure 2.5.1.3 (a) shows dimension used in Airy's equation for bunkers.

Lateral pressure at depth Y:

$$p = 1/2 \, \gamma \, Y^2 \, [1/((\mu(\mu + \mu') + (1+\mu^2)]$$

In which, $\mu = \tan \rho$

Vertical pressure at depth Y: q = p/k

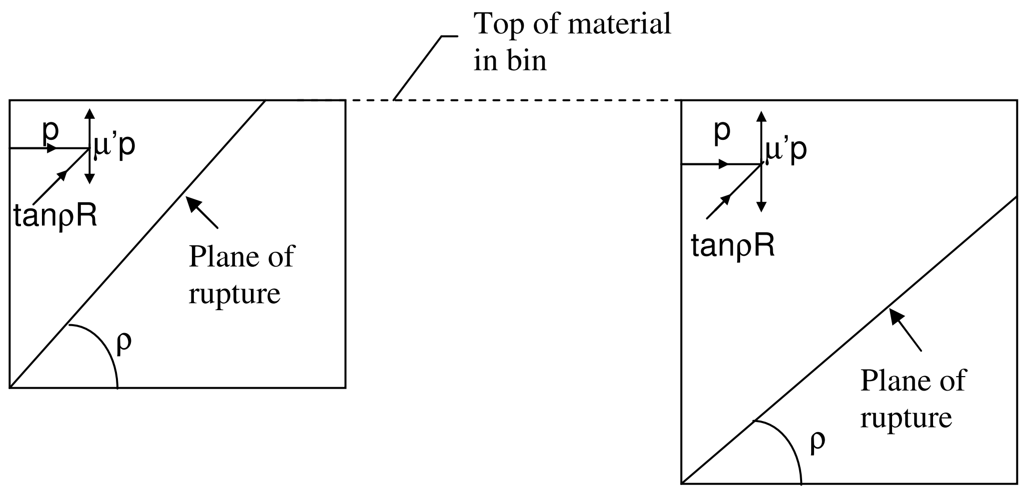


Fig. 2.5.1.3 (a),(b) Dimension for using Airy equation for bunkers and silos

Figure 2.5.1.3 (b) shows similar dimension for silos. Airy's derivation for a silo leads to:

Lateral pressure at depth Y:

$$p = \gamma D/ (\mu + \mu') [1- \sqrt{(1+\mu^2) /((2Y (\mu + \mu') +1-\mu\mu')}]$$

Vertical pressure at depth Y:

$$q = p/k$$

2.5.1.4 COMPARISON OF METHODS FOR COMPUTING STATIC PRESSURE

Static pressures using Janssen's, airy and Reimbert methods for different combination of silo proportion, stored material and friction coefficient between stored material are computed for the silo wall. The limited number of cases considered and the following conclusion may be drawn:

Lateral pressure: For bunkers and the upper portion of silos, the Reimbert method gives the highest pressures and the Janssen's method the lowest. At depth below about 3.2D, however Reimbert's method indicates a lower pressure than Janssen's method.

Vertical pressures: For condition considered in above the Reimbert's method gives the lowest pressures- regardless of silo size, material properties, or position in silo. Likewise the Airy's equation always gives higher pressure.

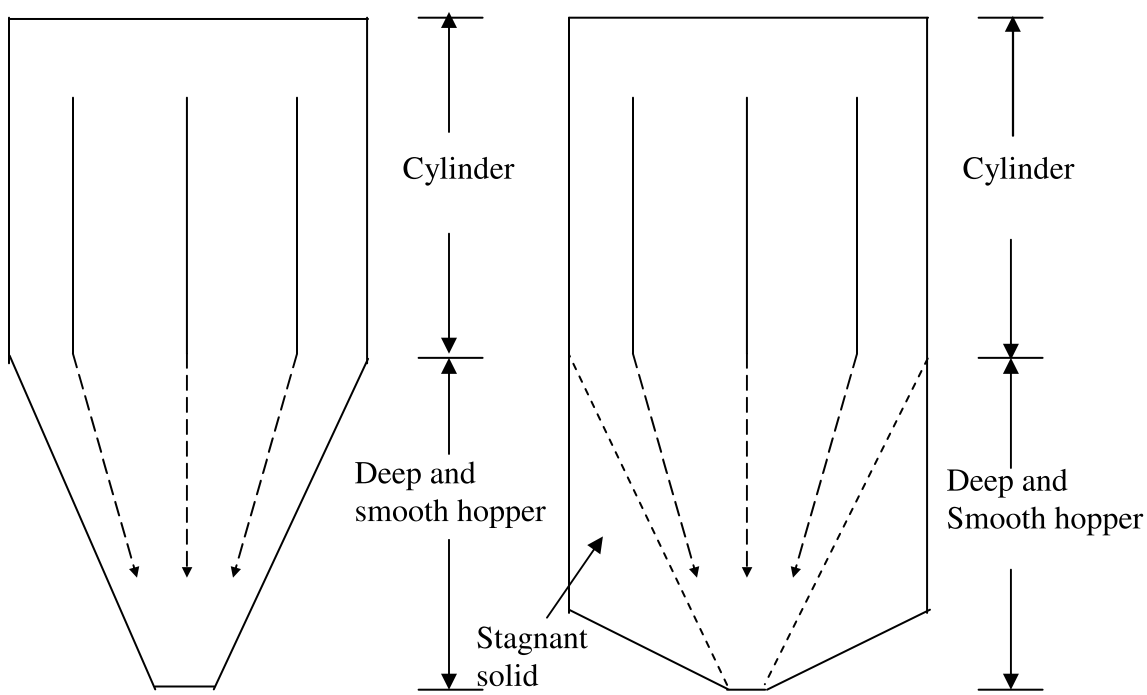
2.6 DIFFERENT FLOW PATTERN

2.6.1. MASS FLOW

This type of flow pattern which occurs when the entire silo contents are set in motion whenever any solid withdrawn from the outlet. This pattern results in a FIFO (first-in, first-out) flow of solid in the silo. The flow rate is uniform and almost independent of the height of the solid in the silo. The entire volume of solid is live with no stagnant or dead zones that do not flow. Mass flow silos must have hopper bottom sufficiently steep and smooth so as to ensure that the entire silo contents flow whenever the outlet is activated.

2.6.2 FUNNEL FLOW

It is a flow pattern, which occurs when the solid is confined to a channel that forms within the basic (stagnant) material. This pattern results in a LIFO (last-in, first-out) flow of the solids in the silo. Funnel flow silos have significantly large dead storage since solids in the dead zones may pack. The silo has to be emptied periodically. In this type of flow pattern there is no sliding on the wall and solid slides on solid. Fig. 2.6.2 (a) and (b) shows basic flow type for mass and funnel flow pattern.



(a) Mass Flow

(b) Funnel Flow
(Core flow)

Fig 2.6.2 Basic flow types

2.6.3 EXPANDED FLOW

Expanded flow pattern features a combination of flow and funnel flow. Flow usually starts within channel above the outlets, similar to funnel flow while the rest of the solid is static. As the silo empties, the static solid sloughs into the flow channel and the silo eventually empties. An expanded flow silo has a hopper consisting of two sections. The lower section is a steep mass flow hopper selected to prevent arching and rat - holing (piping) of the solid. The upper section is a self-cleaning hopper, which permits the solid to slide into the mass flow section as the silo empties.

2.7 ARCHING

Arching occurs when solids from a stable dome or arch across the outlet. Arching will obstruct the flow of solid out of the silo. Arching occurs when either the outlet is not sufficiently large to assure unobstructed gravity flow or the silo is discharged at the maximum flow rate of the system. These conditions require additional analysis and I.S code is not explicit on increase on wall pressure due to arching. All codes agreed that vertical pressure on silo bottom need not be considered more than 100 percent of weight of silo contents. This can be avoided by suitably sizing the outlet.

2.8 RAT-HOLLING (PIPING)

Piping occurs when a stable vertical hole forms within the solid above the silo outlet. Piping will obstruct the flow of the solid.

Certain combination of material properties and silo and hopper geometry may cause harmful flow irregularities such as arching, pulsation or shock and their origin and ways to reduce or eliminated their harmful effects.

2.9 FLOW IRREGULARITIES

2.9.1 PULSATION

Pulsating occurs when the slope of the hopper wall plots in the uncertain boundary region between mass flow and funnel flow. Pulsation result from repetitive formation and collapse of an obstruction to flow. The frequency of pulsation, which is usually between 1/5 and 10 Hz, is directly proportional to the rate of outflow while the amplitude tends to be higher at low flow rates than at high. A pulsation head of stored material above the location of the pulsation source is required; where the head becomes low enough, pulsation ceases. Out flow from a bin during pulsation is uniform. This means that material flow below the pulsation source is continuous

Objectionable pulsation occurs only with materials containing at least a fraction of coarse particles say greater than 0.2 in. Since the designer cannot select the material and transition required in most silos, the designer can only attempt to minimize the amplitude of pulsation.

2.9.2 SHOCKS

Periodic shocks are expected in funnel flow bins containing coarse solids with little fines. Such material would include cement, clinker, coal and corn. In large silos these shocks can be destructive .The interval between shocks is irregular, lasting from several seconds to a few minutes. As a constant outflow rate shock severity increases with the length of the presiding interval. Uniformity of feed rate is not effected by the shocks, but the top level of material in the bin usually remains stationary during the interval, dropping an abruptly during the shock. The shocks diminish in strength and than vanish. This shock densifies the material in the flow channel, which reforms with higher wall pressures capable of stabilizing the material around it. As material discharges the wall pressures decrease and a new collapse occurs.

Shocks can be eliminated or at least minimized by expanding the flow channel to a base diameter. Shocks of this type do not occur in cohesive materials that develop stable stagnant channels. Such material resist shocks through counteracting void air pressure gradients. Severe shocks can originate within a flowing material when the hopper slope and friction are on the boundary between mass and funnel flow. To prevent these shocks hopper slopes should be steep enough so that θ and μ plot continuously in the mass flow region. A stainless steel linear or some times an epoxy coating, or special plastic lining may provide a solution in an existing hopper that is not quite steep enough for continuous mass flow.

2.10 EFFECT OF OPENING - ECCENTRIC FLOW

If the bulk solid in a silo does not flow downwards uniformly across the cross-section but in an eccentric flow zone, then this behavior is called eccentric flow. Typical reasons for eccentric flow are:

- Funnel flow silo with an asymmetrically formed flow zone, especially in the case of an eccentric outlet opening.
- Silo with a feeder, which withdraws the bulk solid only from a part of the outlet opening.
- Asymmetric hopper.
- Silo with more than one outlet opening of which not all are in use.

The non-uniform stress distribution can be explained as follows. A vertical section of a silo (diameter d) with an assumed flow zone (diameter d_f). The bulk solid in the flow zone, which flows downwards, affects not only the silo wall but also the bulk solid at rest (dead zone) with downwards-directed shear stresses i.e. the bulk solid in the flow zone transmits a part of its weight to the silo walls and to the bulk solid at rest (the shear stresses are drawn in their direction of action). Therefore, the stress in the flow zone decreases whereas the stress in the dead zone increases. In reality the situation is more complicated

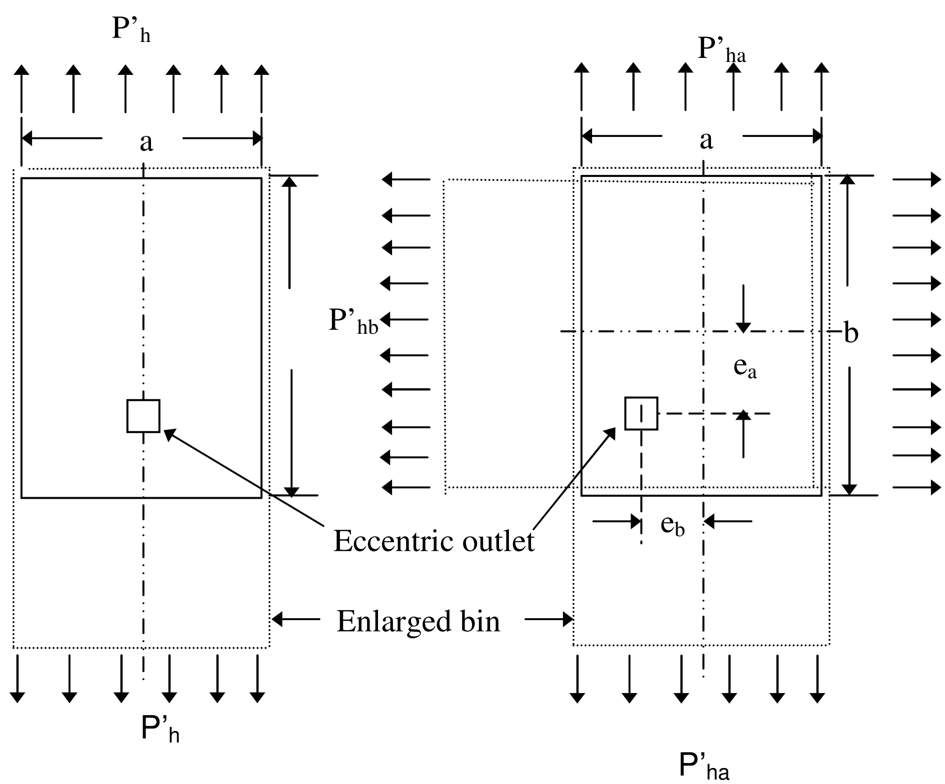


Fig.2.10 (a) RECTANGULAR BIN

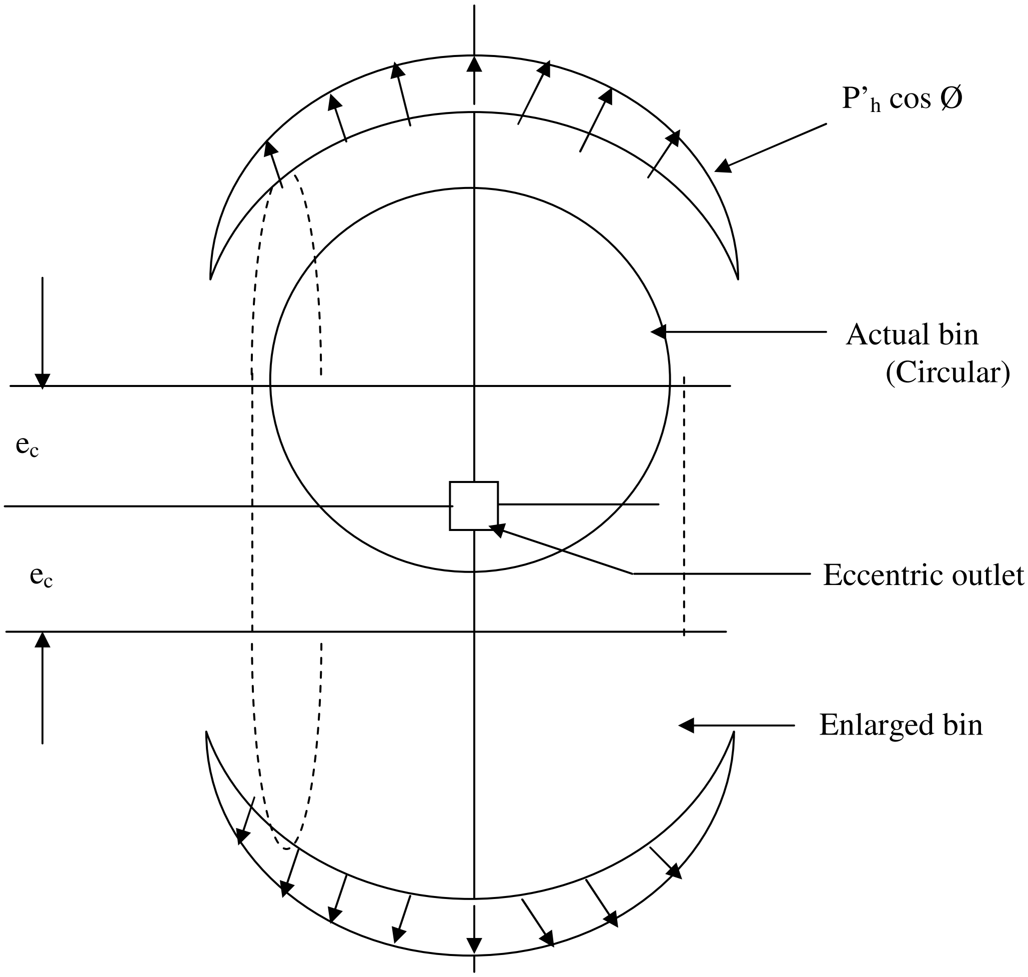


Fig. 2.10 (b) Effect of Emptying through Eccentric outlet in circular bin

Fig. 2.10 (a) and Fig 2.10 (b) show effect of outlet for rectangular bin and circular bin. Experimental study shows that withdrawal of granular and powdery material through eccentric opening causes lateral pressure changes much different from that of concentric opening. Early test shows that the pressure increase due to eccentric discharge compared with that of concentric discharge occurs on the opposite side to the discharge opening eccentricity and that decrease on the side nearer to the opening.

The cause of non-uniform pressure is the nonsymmetrical flow of material and cause horizontal and vertical bending moments, which must be considered in design of silo wall.

The following discussion introduces several approximate methods for computing additional lateral pressure P_{ecc} due to eccentric discharge. Fig. 2.10(c)

ACI 313-77 Approach

Assume the increase of design lateral pressure to be at least 25% of the static pressure at the bottom of the silo when an opening is next to the silo wall. If the eccentricity (e) of the opening from the center of the silo is less than radius (r) consider the increase to be at least e/r times 25% Assume this design pressure increase to constant from the top of the hopper to a height equal to D and to reduce linearly from that point to top of silo The increase need not be multiply by C_d. Expressed as an equation the design pressure at any depth Y below the surface of the stored material would be P_{des}

$$P_{des} = C_d \times P_{st} + P_{ecc}$$

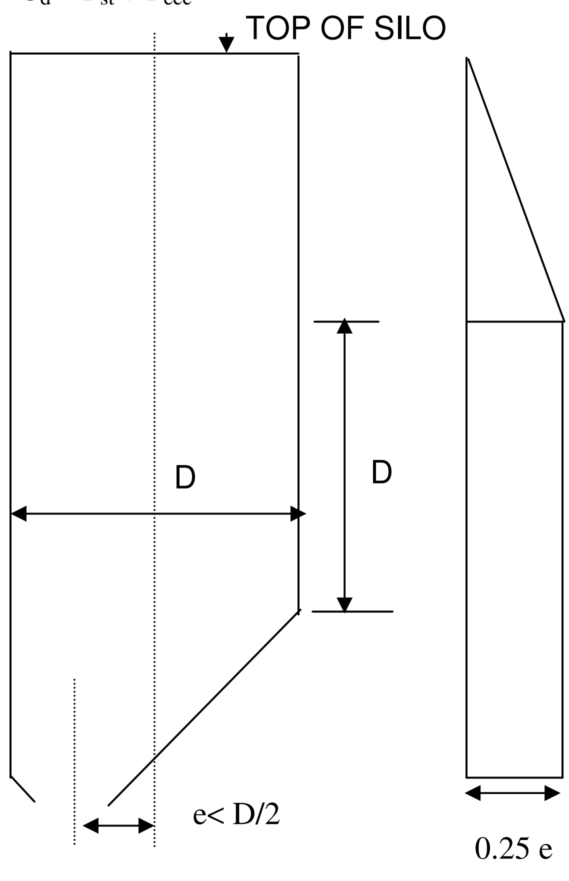


Fig. 2.10 (c) Pressure increase- eccentric discharge

CHAPTER 3. LOAD CONSIDERATION

The principle loads for silo and bunker design come from action of the stored material loads or forces from other sources including; dead load, equipment load wind, floor and roof live loads; seismic loads; forces from thermal effects and forces applied at restrain of attached items.

3.1 DEAD LOAD

It includes weight of silo it self- walls, roof, ring beam, hopper – plus the weight of item supported by the silo. These loads include inside and outside stairway and service platform, equipment on silo roof overhead gallery etc.

Many of these dead loads can only be estimated in the early phase of design. Dead load of silo bottom that rest on independent support should be separated from those affecting the silo walls.

3.2 LIVE LOAD

Pressures due to stored material are treated as a live load. Live load on platforms, roof, and floors should be as required by applicable building code or larger. To determine the wall load the designer must know the flow condition. Different methods of determining design pressure must be used according to whether the flow is funnel flow, mass flow or some other type.

Aeration may be used to cause a semi fluid condition in the stored material. Pressure intensity in that case is express as

$$P = 0.6\Upsilon \text{ x } Y$$

In which,

Υ = Weight per unit volume

Y = depth of aerated material.

3.3 EQUIPMENT LOAD

Equipment item may apply severe live load on the structure. Theoretically equipment manufacture should be able to predict the load their equipment will imposed but if this equipment is vibrating it may bring out changes in other loads. For example the stored material may become compacted acquiring higher density and altered flow characteristic with resultant changes in lateral and vertical pressure.

Belt conveyor and their support system can bring large live and dead load to a silo.
It is recommended that pinned or fixed connection of conveyor support to a silo roof not be allowed.

3.4 WIND LOAD

All silo structure should be designed resist the overturning effects caused by wind or earthquake forces. Wind and earthquake load should not be assumed to act simultaneously. Which ever is the more will be taken in design. Practically all codes permit an increase of allowable stresses and soil bearing values when either wind or earthquake acts alone or in combination with the dead load and live load. Most building codes allow a one third increase above the usual values permitted.

Wind load for silo can be in any lateral direction and generally should be considered as positive pressure on the wind ward side and negative on lee ward side Foundation pressure and column stresses may be the worse cases with wind acting on the full silo the following reduction factor may be applied depending on cross sectional shape.

Hexagonal or octagonal single silo	0.8
Round single silos	0.6.

No reduction factor should be applied to silo groups.

3.5 SEISMIC LOADING

Earthquake load may affect both stability and strength of silo and bunker. Walls and columns supporting silos and bunkers may be particularly vulnerable to earthquake forces.

In the absence of better code requirement on seismic design of silo to resist lateral load different approach is given by ACI313-77 on silo and bunker. The suggested approach is based on the following assumptions.

1. Seismic forces can act in any horizontal direction. Vertical seismic force is neglected for most aspect of seismic design.
2. Only a fraction of the stored material weight need be considered when computing seismic forces. For simplicity the seismic forces on the fraction is treated as lateral static force applied at the centroid of the entire stored mass and acting in any horizontal direction. Generally 80% of the weight of the stored material as an effective weight, W_{eff} on which to base computation of lateral force.
3. The weight of the stored material in a suspended hopper should not be reduced to an effective weight value.

4. When silo bottom are on support that are independent of the silo walls these two independent structures will share the lateral force from seismic action on the effective weight W_{eff}.

3.6 LOADS DUE TO THERMAL EFFECT

Two types of thermal effect may need to consider. The first is a through the wall temperature gradient important in concrete wall cause by storing material. That is much higher than the air temperature around the silo.

Daily temperature changes due to intense sunlight may cause expansion and contraction of silo groups. Stresses due to this action are large enough so cause wall to crack. Seasonal temperature change can have similar effect. Steel silo can fail by daily thermal expansion and contraction. Thermal stresses have to be considered during design process.

The temperature of hot material in silo is not uniform, but drops appreciably near the inside wall. This drops may be considered when determining the design temperature different ΔT, between inner and outer wall faces.

$$\Delta T = T_2 - T_1$$

T_2 and T_1 may be calculated by heat transfer equation $Q = U \times A \times (\Delta T)$

Where,

Q = heat transfer (kg/hr)
U = heat transfer coefficient
A = Area of the cross section of wall

The temperature different ΔT within the wall is a portion of the total design temperature difference corresponding to K_t, the ratio of the thermal resistance of the wall alone to that of the cement, wall, and outside air combined.

$$\Delta T = K_t\,[Ti_{des} - T_o]$$

The determination of K_t is by the heat transfer principle Factor K_t for various thicknesses is taken by curve as shown in fig 3.6(a).

The ultimate thermal bending moment is calculated as per code guidelines and required area of steel reinforcement is provided in case of R.C.C silo. The area of steel should be located near the outer (colder) face. Vertical tensile thermal stress is usually offset by vertical dead load compressive stresses so that added vertical temperature steel for the effect of hot material is normally not need.

IS 4995 has given formula as below

$$\Delta T = t/Cc \times (Ti-To)/(1/k);\ 1/k = 1/Ca + t/Cc + 1/Cs$$

Where,

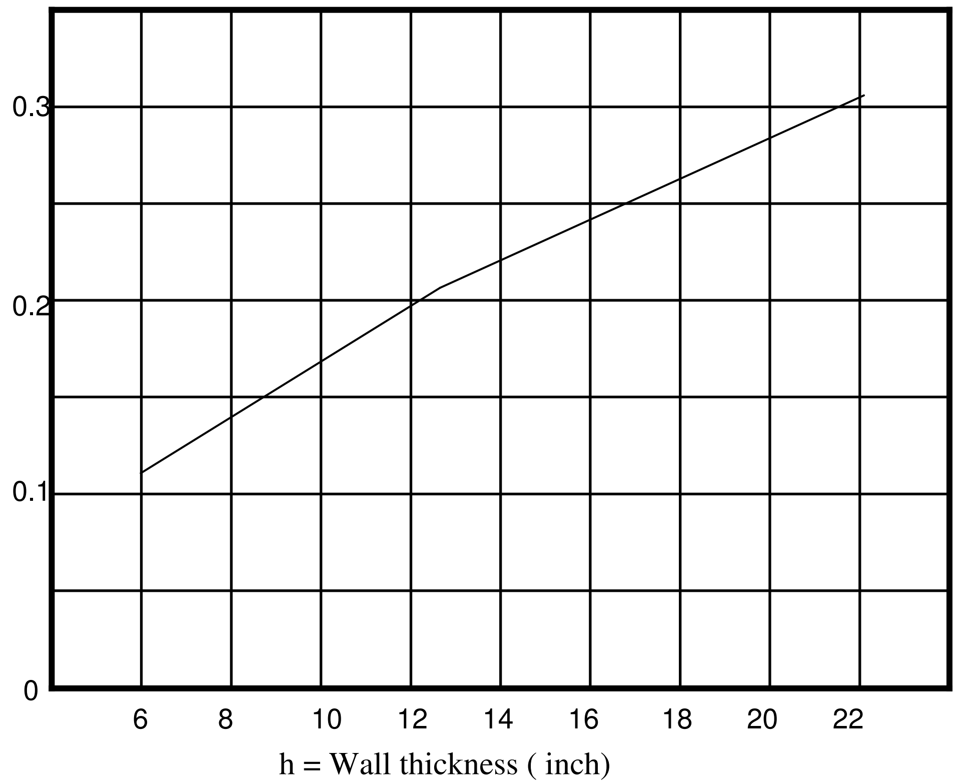
t = thickness of bin wall in m

C_a = surface conductance of concrete to air =15 in kcl/m^{2}h° C

C_c = thermal conductivity of reinforced concrete =1.75 to 2 in kcal/m°h

C_s = Surface conductance of concrete to stored material = 2 kcal/m^2 h° C

Kt={0.08h/94.09-0.08h)}



(a)

Fig. 3.6 Temperature Drop through Wall – ACI Method

Stresses and bending moment as per IS 4995

Bending moment due to change in temperature is calculated as per following expression

$$M\,\Delta T = E_t \times \Delta T \times E_c \times I / t$$

Where,

E_t = Coefficient of thermal expansion of concrete = 11 x 10^{-6} / per degree per cm

E_c = modulus of elasticity of concrete = $18000\sqrt{\sigma cu}$; Kg/ cm^2

I = moment of inertia of the bin wall

3.7 LOADS FROM EXTERNAL RESTRAINTS

A silo is a flexible membrane. The walls of an isolated circular silo under uniform internal pressure around its circumference expand radialy. Such a membrane has high horizontal membrane tensile stresses, but no horizontal bending moment.

However if at any point the silo wall is attached to something that restrain its radial movement, the wall is dented and significant horizontal and vertical bending moments occur. These bending moment when their effect is added to the hoop tension and vertical compression could cause wall failure. Often the silo designer becomes aware of the connecting item only after the main silo design has been completed. At that time it may be inconvenient to proper provisions in the design.

3.8 LOAD COMBINATIONS

The designer should consider all reasonable load combination. Combination that is extremely improbable usually neglected. Table shows a matrix of load types and suggested combinations for silo and bunkers. Combination not shown would ordinarily be ignored.

Table 3.8 Load combinations for silos and bunker design.

	Combination				
Type of load	A	B	C	D	E
Dead load	X	X	XX	XX	XX
Floor and roof live load	X	±		X	
Material pressure					
Static	X	X		X	
Overpressure	X	X		X	
Thermal loads	X	X		X	
Equipment loads	X	X		X	
Wind loads		X	X		
Earthquake loads				X	X
Restraint loads	±			±	

X : consider

XX : consider but reduce if required by code.

± : consider or neglect which ever is more severe

CHAPTER 4. CONCRETE SILO

4.1 PERMISIBLE STRESSES

4.1.1 STRESSES IN CONCRETE

The permissible stresses in tension (direct and due to bending) and shear shall conform to the values specified in table1 (cl 5.4.1.) of IS 4995 (Part II). The permissible tensile stress due to bending applies to the outside face of the bin. In members less than 225 mm thick and in contact with material on one side, the permissible stresses in bending are also applicable to side in contact with the stored material.

4.1.1.1 STRESSES IN CONCRETE FOR RESISTANCE TO BUCKLING

The maximum compressive stress on net wall section deducting all wall opening, recesses, etc shall not exceed 0.25 σ_{cu} where σ_{cu} is the compressive strength of concrete at the age of 28 days.

4.1.2 STRESSES IN STEEL REINFORCEMENT

The permissible stress in steel reinforcement shall conform to the value in table 2 (cl. .4.3 IS 4995, Part II).

4.1.3 INCREASE IN PERMISSIBLE STRESSES

Where stresses due to wind or earthquake are combined with those due to dead load, live load and impact loads and temperature and shrinkage effect the stress may be exceeded up to a limit of 33.33 percent.

4.2. WALL REINFORCEMENT

Wall reinforcement must serve three purposes:

1. It must strengthen the wall to resist the computed forces and bending moments resulting from the stored material and other loadings.
2. It must distribute tensile cracking so as to keep crack width within permissible limits.
3. It must resist vertical and horizontal bending moments so as to distribute the effect of local concentration of pressure to a larger area of silo wall.

Vertical bending moment may cause horizontal cracking. Such bending moment can result from non-uniform pressure on the walls, from temperature difference between stored material and outer wall surface or from external concentrated loads. Vertical steel to resist these bending moments also provides supports for the horizontal steel.

4.2.1 VERTICAL REINFORCEMENT

Vertical reinforcement in silo walls has an important function of aiding to distribute lateral load irregularities vertically to successive layers of horizontal reinforcement. It serves to resist vertical tension due to following causes.

1. Temperature or moisture changes in the wall when the wall is restrain or not free to move in vertical direction.
2. Vertical bending moment at levels where the wall is restrained against circular elongation.
3. Vertical bending moment due to eccentric loads, such as those from hopper edges or attached auxiliary structures.
4. Vertical bending moment due to concentric loads at the transition of a "material hopper" during unloading.
5. Temperature differentials between inside and outside wall surfaces or between silos.

4.2.2 HORIZONTAL REINFORCEMENT

Horizontal reinforcement in circular silos or bunker is usually in a single layer for walls up to about 8in. thick. Such reinforcement and wall thickness are found in small to moderate size structure up to about 30ft in diameter. Larger structure more in thickness should have two layers of reinforcement. Location of reinforcement within the wall thickness is important. A structural advantage of having horizontal reinforcement near the outside and inside face of the walls increases the effective depth d, the steel will more effectively resist horizontal bending. Two-layer reinforcement is recommended especially for silos of moderate or large diameter.

4.2.3 REINFORCEMENT AROUND WALL OPENING

Major wall opening in silos are usually confined to walls below the bottom structure. They range from small opening from ducts or pipes, to opening for belt conveyors to those for passage of large trucks or railway cars.

From the structural stand point it is a good practice:

1. To keep the total area of openings as small as possible.
2. To avoid having several openings along the same vertical line or at the same elevation (especially if they remove an appreciable height or length of wall)
3. To keep large openings well below the silo or bunker bottom structure.

To avoid trouble at the top of wide openings in the lower walls Safarian and Harris suggest that the top of these openings be should be far below the bottom component of the silo. That distance should preferably be not less than the largest of the following.

1. Two third of the opening width.
2. Three times the wall thickness.

Extra reinforcement around the opening should be provided and the section should have additional reinforcement. This added reinforcement serves four purposes:

a) To help the wall above a wide opening to span as a beam infact acting as lintel.
b) To transfer horizontal tensile force from one side of the opening to the other.
c) To strengthen the wall at each side of the opening so that it can carry vertical force.
d) To control cracking and to take care of stress concentration at corners.

The recommendations given by ACI 313 are as follows.

a) At openings in the pressure zone (container part): replace all horizontal reinforcement with 1.2 times that is intercepted by the opening. Half of this horizontal reinforcement is placed above the opening and the other half below the opening.
b) At openings not in the pressure zone (supporting system): replace all horizontal reinforcement that is intercepted by the opening. Half of this horizontal reinforcement is placed above the opening and the other half below the opening.

4.2.4 SPLICES OF REINFORCEMENT

Reinforcement in silos and bunkers normally is lap-spliced. Horizontal reinforcements are spliced for tension. Vertical bars may have only compression splices, in case of lateral loads or vertical bending moment the bars are in tension and in this case tension splice is needed.

A tension lap splice may be a starting point for failure particularly if the concrete cover over the bars and the spacing between bars are both small. If all hoop bars in a circular silo were lap spliced at the same location of the wall circumference, a plane of weakness would be started and extended for the full height of the silo.

To overcome to this problem ACI 313 require that hoop reinforcing splices in circular wall be staggered horizontally by at least one lap length (l) or three feet. That laps not coincide its position more frequently than every third bar as shown in Figure 4.2.4

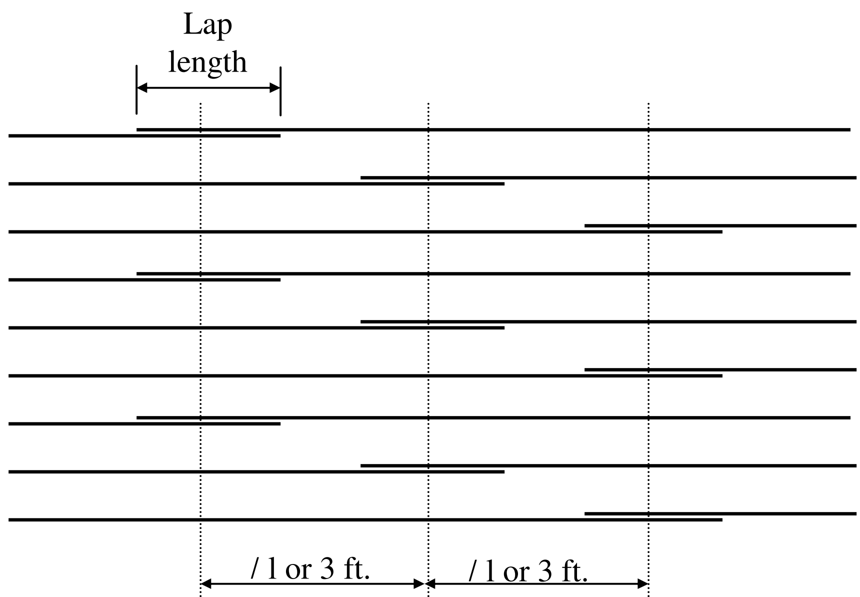


Fig 4.2.4. Hoop splices

4.2.5 DETAILING PRACTICE FOR WALL REINFORCEMENT

While finalising design and detailing, the designer should keep in view the construction aspect of silo. The following table is based on the recommendations given in IS code. Where IS code is not specific, recommendations of ACI are given.

Table 4.2.5 Detailing practice - Wall reinforcement

	Circumferential (hoop) steel	Vertical steel External wall of single or multi cell silo	Vertical steel Internal wall of single or multi cell silo
Minimum steel (% of gross area of wall)			
Deformed	0.25	0.20	0.15
Plain	0.30	0.25	0.20
Spacing (mm)			
a. Maximum			
Single row	200	225	300
Double row	400*	450*	600*
b. Minimum			
Single row	75	75	75
Double row	100	100	100*
Minimum bar diameter (mm)			
Deformed	8	10	10
Plain	10	12	12
Cover (mm)			
Minimum	30	30	30
Maximum	40	40	40
Location	Outer face of wall	Tied inside to hoop steel	Tied inside to hoop steel
Hoop steel Extension below pressure zone	Distance equal to 6 times wall thickness		
Staggering of splices	At least one lap length or one meter		

4.3 BOTTOMS FOR CONCRETE SILO

Bottoms of the concrete silos are of many types such as:

1. A horizontal slab with one or more discharge opening
2. A concrete hopper of conical, pyramidal or other shapes
3. An inverted reinforced concrete cone with multiple discharge opening
4. A steel hopper

Silo bottoms may be supported by the silo walls, by separate bottom-supporting walls that extended down to the foundation, by pilasters connected to the lower silo walls, by independent columns or by a combination of these. In some cases, the foundation mat itself serves as the silo bottom. Selecting a silo bottom is a question of economy and the method of material withdrawal to be used. Self-cleaning silo bottoms should have a smooth inside surfaces and their inclined wall should have a slope steeper than the angle of the material to be stored.

4.3.1 CONICAL CONCRETE HOPPERS

The conical concrete hopper may be rigidly attached to the silo wall but ordinarily is supported by a concrete ring beam around the upper perimeter of the hopper. The bottom of the cone preferably should not be restrained or supported. The conical hopper shell is subjected to two tensile membrane forces. The tangential force is in the plane of shell and horizontal. The meridional force per unit width at depth Y is computed from equilibrium of the loads on the cone below that depth. The total meridional tension at any horizontal plane passing through the hopper shall be such that its vertical component is equal to total vertical pressure on that plane plus the self-weight of the hopper and its content below the plane. The meridional reinforcement shall extend sufficiently into the vertical wall to secure adequate bond. The hoop tension at any level of the conical hopper shall be determined as follows:

$$\text{Hoop tension} = r_h P_n \operatorname{cosec}\alpha$$

Where,

r_h = radius of hopper at the plane under consideration,

P_n = normal design pressure at the plane under consideration

Both meridional and tangential forces are maximum at the upper edge of the silo hopper and approach zero at the lower edge. The minimum acceptable thickness for the cone would be determined considering the acceptable crack width as for silo wall.

4.3.2 PYRAMIDAL CONCRETE HOPPERS

Pyramidal hoppers are used in rectangular silos and can be supported by edge beams or by being built with the silo walls. A structural disadvantage of the pyramidal hopper is that its walls are subjected to both biaxial tension and two- way bending. Further the hopper walls may also have in plane bending when they are flexurally continuous with the silo walls above and when the silo walls have large openings immediately below.

4.3.3 BOTTOM OF THE OTHER SHAPES

As per the IS 4995 the bottom of other shapes such as bottom with one or more sloping sides with the remaining sides vertical, Bottoms provided with special emptying arrangements etc. shall be designed based on principle of mechanics and sound engineering practice. Bottom of other shape like inverted cone is also used to keep more space below the cone for handling material and can be possible to keep supporting system height as less as possible.

4.4 SPECIAL SILOS

4.4.1 DOUBLE CYLINDRICAL CONCENTRIC SILO (RING SILO)

A small inner silo within another of larger diameter as shown by figure 4.4.1 is occasionally used in the sugar and cement industries. In the cement industry cement clinker is usually stored in the outer cylinder between while masonry, cement, lime stone, gypsum, special grind clinker or similar material is stored in the inner cylinder.

The stored material loading in ring silo is considerably different from the loading in single silo. Particularly difference is the behavior of the material stored between the inner and outer silo walls.

The simplest approach for computing pressure from the material between the silo walls is to assume the container between the outer and inner wall to be similar to a rectangular silo. This assumption is considered reasonable by the fact that the hydraulic radius of both cross sections is same. For a rectangular cross section with hydraulic radius R is equal to one half of the short length and for ring silo hydraulic radius R is equal to one half of the difference of the radius as shown in Figure 4.4

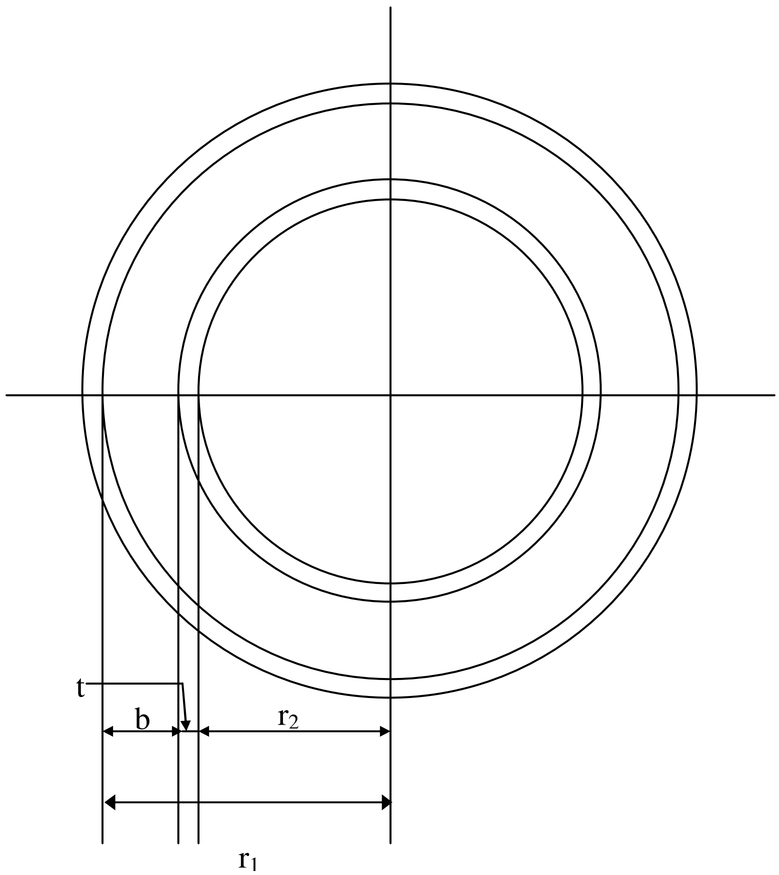


Fig 4.4.1 Ring silo cross section

$$\text{Area of outer silo} = \pi\,[r_1^2 - \{r_2 + t\}^2]$$
$$\text{Perimeter of outer silo} = 2\pi\,[r_1 + \{r_2 + t\}]$$
$$R = \text{Area/Perimeter}$$
$$= b/2$$

4.4.2 HOMOGENIZING OR BLENDING SILO

Homogenizing silos have been developed to meet the need for large volume storage along with blending or homogenizing of a wide range of dry pulverized free flowing materials that require homogeneity in the process flow. These silos provide functions, storage and blending in a single unit. Such silos can be of either steel or concrete. They can be built as single silo or two or more silo. Some of which may have multistory compartment.

Once a loading is determined there is little difference between structural design procedure for blending and homogenizing silos and those for ordinary storage silos. The walls of both concrete and steel blending silos should be airtight. In concrete silo special attention should be given to joints between wall and roof slab and between wall and bottom slab. A sealing compound should be selected to assure a permanent seal.

4.4.2.1 PRESSURE IN HOMOGENIZNIG SILO

By extensive study on the behavior of powdery material in silo under aeration and homogenizing condition several conclusions have been made.

1. In the homogenizing chamber the material behave as a liquid having a hydrostatic pressure distribution equal to that of a liquid whose unit weight is 0.6 times the unit weight of the unaerated actual material.
2. High speed filling of powdery material especially in narrow silo may produce higher lateral pressure more than pressure due to normal gravity filling. Marten found that the lateral pressure due to such high speed filling is a function of the velocity of the material. V_f and a factor C_f that depends on the nature of the powdery material. Marten equation for the lateral pressure occurring during such filling is as under.

$$P \text{ filling} = \gamma C_f \, V_f \; (KN/m^2)$$

In which, V_f in m/hr.

γ = Density of material

4.4.3 PRESTRESSED CONCRETE SILO

Large circular silos require prestressing to counteract the hoop tension. Prestressing is essentially required for the wall of rectangular silos, which are subjected to tension and bending. Also in silos for the storage of cement and clinker, large inside temperatures are encountered which result in considerable expansion of the cell walls. The restraining of which would lead to considerable bending moments. These cannot be balanced without cracking unless prestressing is applied. Vertical bending moments also developed due to the arching of the stored solid and hence the walls are to be prestressed both horizontally and vertically.

4.4.4 FIBRE-REINFORCED PLASTIC SILO

Recently FRP silos have found favourable in the plastic industry for the storage of polymeric products. The smooth non-corrosive finish of the internal wall ensures non-contamination of the product and the low wall friction minimizes potential hold up during discharge. FRP is tough, impact resistant and is generally not affected by ageing or weathering. It is also simple to anchor brackets, nozzles, man ways and other attachments to the FRP silo during manufacture.

4.5 CONSTRUCTION METHODOLOGY FOR SILO

The design boundary conditions will depend upon the method of construction. The following two methods of constructing silo with central cone are possible:

1. Entire wall is slipformed from top of foundation. At the junction of change of section of wall formwork is altered. Cone is constructed later.
2. The above method is possible only in case of single cell circular silo. In case of ring or compartment silo, the inner wall is supported on central cone. In such case lower portion of silo wall and cone with ring beam are constructed first up to level of starting of inner wall. Silo walls (outer and inner together) are slipformed from this level.

The cone is constructed with inside formwork on scaffolding. Insert plates can be left in lower part of silo wall to support formwork girders, resulting in reduced height of scaffolding. The scaffolding need not be design for full weight of fresh concrete of the cone, as it is concreted in ring shaped sections. Sections already cast, carry load of next sections. In view of this advantage of conical shell, precasting is also feasible even for large size of cone.

4.5.1 SILO CONSTRUCTION TOLERANCES

Tolerance limits as recommended in ACI code are given below:

1. The maximum horizontal deviation (which may consist of translational and rotational components) of any point on the structure relative to a corresponding point at the base of structure shall be not over 8 cm at any location for 30 m height silo, nor over 10 cm for silos over 30 m height.
2. The variation from true circular cross section in a circular silo and the variation from prescribed diameter shall be not more than 2.5cm or 4mm /m of diameter, whichever is larger, but in no case more than 7.5cm.
3. The variation from prescribed inside width dimensions for noncircular silos shall not exceed 4 mm/m of width nor 5 cm total.
4. The variation from prescribed wall thickness shall be in the range from 1cm to 2.5cm.

4.6 PARAMETRIC STUDY (EFFECT OF OPENING)

In structures like bunker and silo several components of the structure like angle of cone to horizontal, inlet and outlet size, inlet and outlet position, stored material behavior etc. make significant effect on structure design.

Here this parametric study shows effect of opening in structure design. In this study there are four openings in outer silo and four openings in inner silo of size 0.5 m ×0.5m as shown in figure 4.6.1

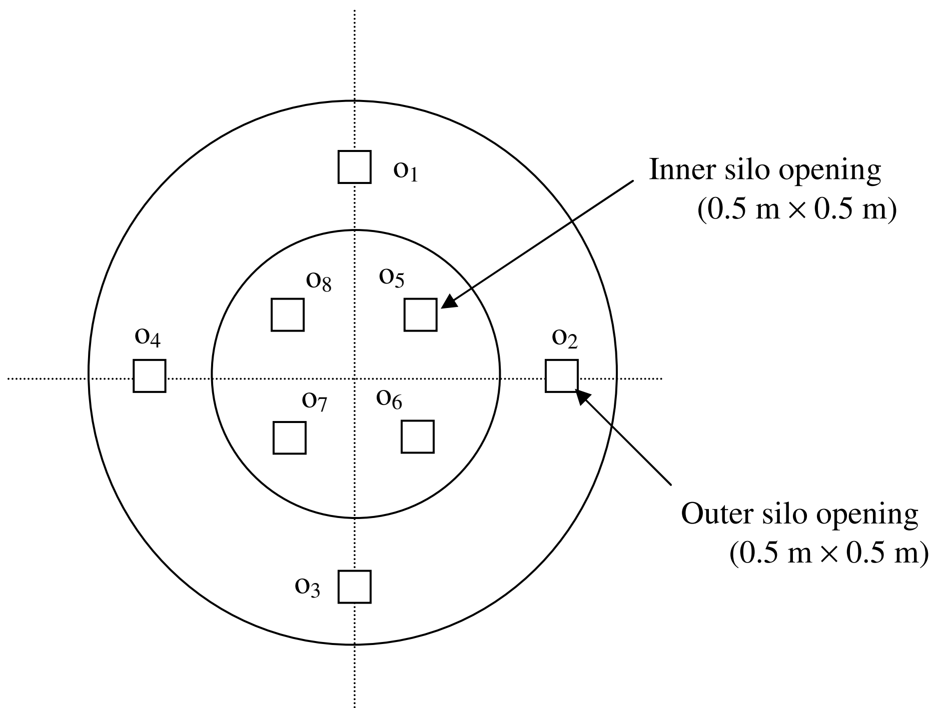


Fig. 4.6.1 Opening position in inner and outer silo

Different cases:

1. Opening o_1 open
2. Opening o_1 and o_2 open
3. Opening o_5 open
4. Opening o_5 and o_6 open

Here for all above cases lateral pressures are calculated as per IS 4995
Diameter of outer silo = 22 m
Diameter of inner silo = 15 m
Opening size = 0.5 m × 0.5 m

Case 1. Opening o_1 open (Outer silo opening Fig.4.6.2)

In this case outer silo opening o_1 is considered open and other three are closed. Here as o_1 is not symmetrical about x-x axis it makes eccentric flow and eccentricity is about x-x axis as shown in Figure 4.6.2

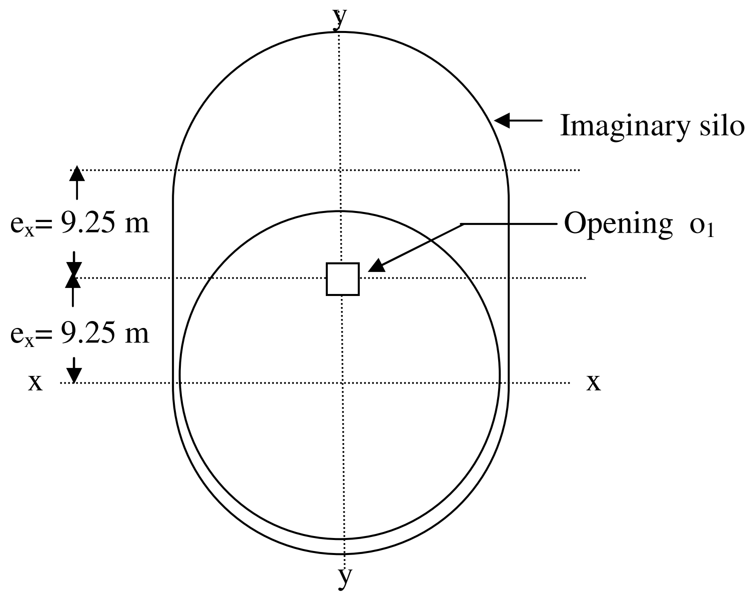


Fig. 4.6.2 Eccentric flow due to opening o_1

e_x = Eccentricity about x-x axis = 15/2 + 3.5/2 = 9.25 m
Area of imaginary silo A = $\pi/4\ (22)^2 + (9.25\times2)\times22 - \pi/4\ (15)^2$ = 610.42 m^2
Perimeter of silo P = $\pi\times22 + (9.25\times2\times2)$ = 106.113 m
Hydraulic radius R = A/P = 5.75 m

Lateral pressure Phi (imaginary silo) for empty condition

$$P_{hi} = w\ R\ /\mu_e(1- e^{-Z/Zoe}) = 16\times5.75/0.26(1- e^{-30/21.94}) = 263.69\ kN/m^2$$

Lateral pressure Ph for empty condition

$P_{h\ z=30}$ = 95.52 kN/m^2 [Ref. Design problem page. No]

Additional pressure $P_{h'} = P_{hi} - P_{h\ z=30}$ = 263.75 – 95.52 = 168.17 kN/m^2
Design pressure = $P_{h'}\cos\phi$ = 168.17 cos 25° = 152.41 kN/m^2

Case 2. Opening o_1 and o_2 open (Outer silo opening Fig.4.6.3)

Eccentricity about x-x axis e_x = 9.25m
Eccentricity about y-y axis e_y = 9.25m

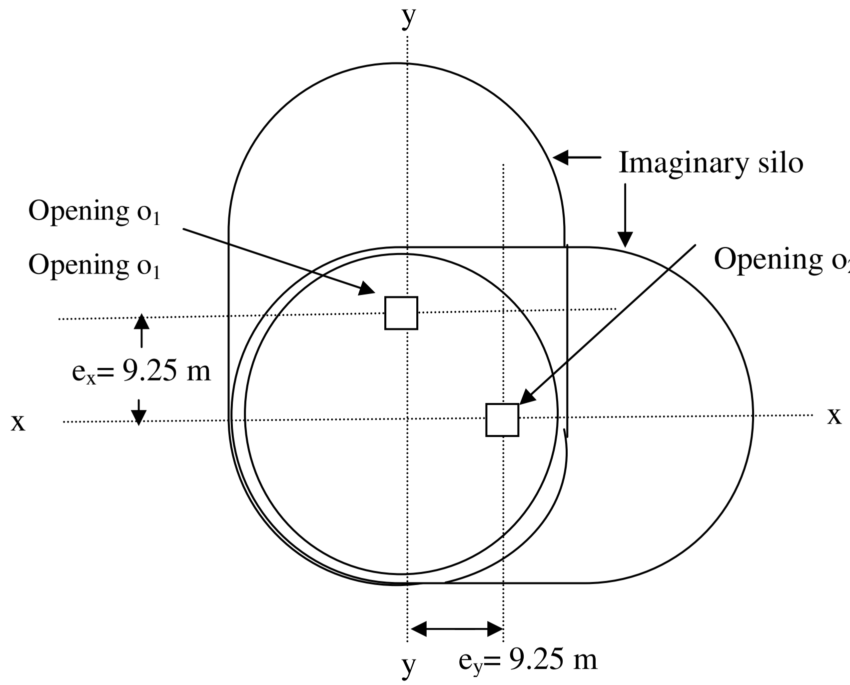


Fig. 4.6.3 Eccentric flow due to opening o_1 and o_2

Here P_{hi} due to e_x (opening o_1) and P_{hi} due to e_y (opening o_2) are same as calculated in case 1.

P_{hi} (due to o_1) = P_{hi} (due to o_2) = 263.69 kN/m^2
Area (due to o_2) = $\pi/4\ (22)^2 + (9.25\times2)\times22$ = 393.56 m^2
Perimeter = 140.14 m
Hydraulic radius R= Total Area/Perimeter = 393.56 + 610.42 /140.14 = 7.164 m
$P_{hi} = w\,R/\mu_e(1- e^{-Z/Zoe}) = 16\times7.164/0.26(1- e^{-30/30.19})$ = 277.65 kN/m^2
P_h = 95.52 kN/m^2

Additional pressure $P_{h'}$= 277.65 – 95.42 = 182.23 kN/m^2
Design pressure = $P_{h'}\cos\phi$ = 183.23 cos 25° = 165.156 kN/m^2

Case3. Opening o_5 open (Inner silo opening Fig. 4.6.4)

Eccentricity about x-x axis $e_x = 3.75$ m
Eccentricity about x-x axis $e_y = 3.75$ m
Area of imaginary silo $A = \pi/4\ (15)^2 + (5.3\times2)\times15 = 335.71\ m^2$
Perimeter of silo $P = \pi\times15 + (5.3\times2\times2) = 68.32$ m

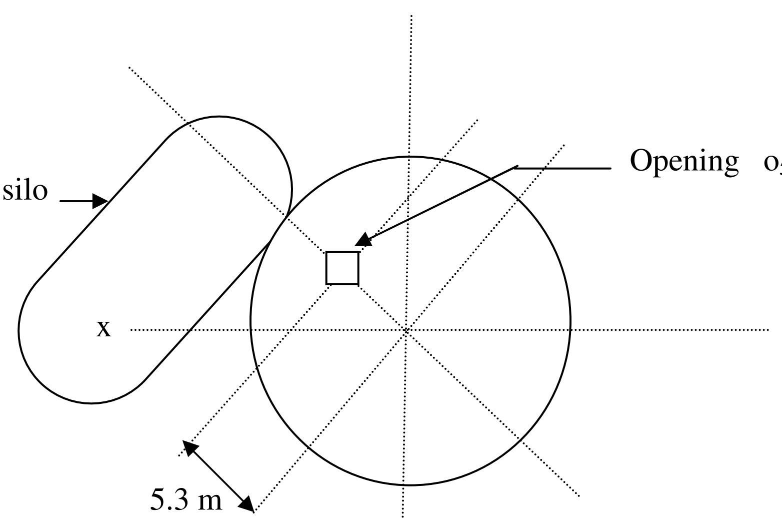


Fig. 4.6.4 Eccentric flow due to opening o_5

Hydraulic radius $R = A/P = 335.71/68.32 = 4.91$ m
At z = 20.78 m,

$P_{hi} = w\ R\ /\mu_e(1- e^{-Z/Zoe})$

$= 16\times4.91/0.26(1- e^{-20.78/18.74}) = 200.92\ kN/m^2$

$P_h = 172.4\ kN/m^2$

Additional pressure $P_{h'} = 200.92 - 172.4 = 28.54\ kN/m^2$
Design pressure = $P_{h'} \cos\phi = 28.54\cos 25° = 25.87\ kN/m^2$

Case 4. Opening o_5 and o_6 open (inner silo opening)
Eccentricity about x-x axis $e_x = 3.75$ m
Eccentricity about x-x axis $e_y = 3.75$ m

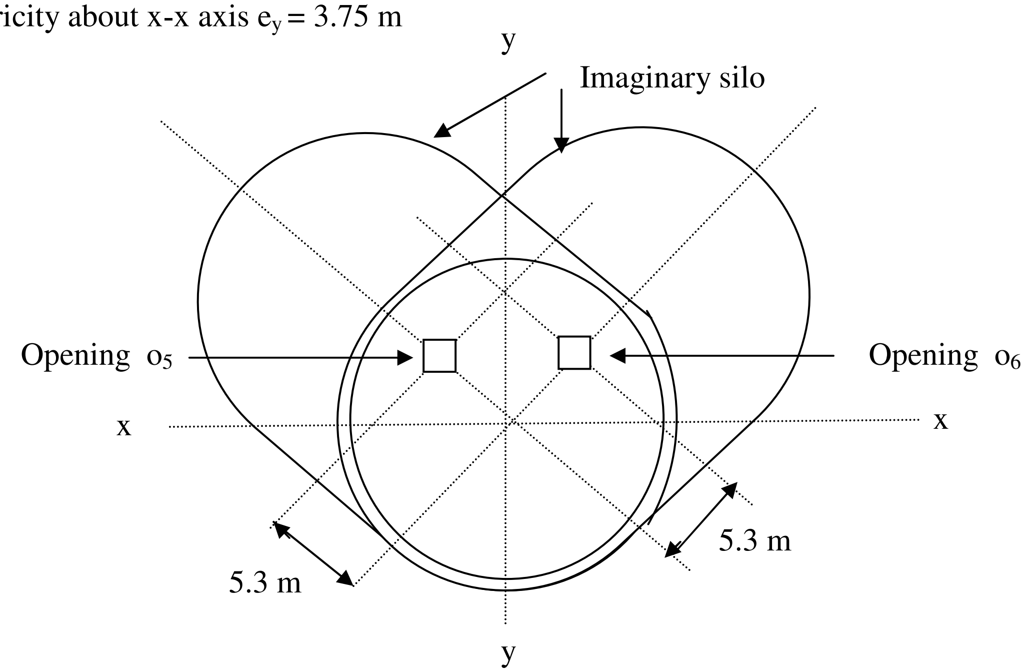


Fig. 4.9.5 Eccentric flow due to opening o_5 and o_6

Area of imaginary silo A = $\pi/4\ (15)^2 + (5.3\times2)\times15 + \pi/4\ (15)^2/\ 2 + 7.5\times15 = 536.56\ m^2$
Perimeter of silo P = $\pi\times15 + (5.3\times2\times2) + \pi\times15\ /4 + 7.5 + 7.5 = 95.10$ m
Hydraulic radius R = A/P = 536.56/95.10 = 5.64 m
At z = 20.78 m,
$P_{hi} = w\ R\ /\mu_e(1- e^{-Z/Zoe}) = 16 \times 5.64\ /0.262(1- e^{-20.78/21.52}) = 213.29\ kN/m^2$
$P_h = 172.4\ kN/m^2$
Additional pressure $P_{h'} = 213.29 - 172.4 = 40.89\ kN/m^2$
Design pressure = $P_{h'}\cos\phi = 40.89\cos 25° = 37.06\ kN/m^2$

CHAPTER 5. DESIGN OF RING SILO

DESIGN DATA:

Design a Ring silo to store O.P.C. (Ordinary Portland cement) and P.P.C. (Pozzolinic Portland cement) of total capacity 13,500 tons.

O.P.C. capacity = 8000 tons
P.P.C. capacity = 5500 tons
Angle of Internal friction $\phi = 25°$ [Ref. I.S. 4995]
Angle of inverted cone with horizontal = 60°
Density of cement = 1600 kg/m^3

General arrangement:

For silo $H/D > 1.5$
Let us take $H = 1.5 \times D$
Volume of cylindrical portion = $\pi r^2 H = \pi r^2 \times (1.5 \times D) = \pi r^2 \times 1.5 \times 2 \times r = 9.4245 r^3$
Volume of Inverted cone = $1/3 \pi r^2 h = 1/3 \pi r^2 \times r \tan 60° = 1.8137 r^3$
Actual volume = Volume of cylindrical Portion - Volume of Inverted cone
$= 9.4245 r^3 - 1.8137 r^3 = 7.61 r^3$ (1)

Volume required = Capacity to store material / Density of material
$= (13{,}500 \times 1000) / 1600 = 8709.67 m^3$ (2)

Comparing (1) and (2)
$7.61 r^3 = 8709.67; r^3 = 4802.16; r = 10.46; D = 20.91$
So keep D = 22 m [For outer silo]

Inner silo capacity = 5500 tons
$7.61 r^3 \times 1600 = 5500 \times 1000; r^3 = 467.12; r = 7.76$
So keep D = 15 m [For inner silo]

Now,
$H/D > 1.5; H = 1.5 \times 22 = 33$ m
$h = r \tan 60° = 11 \times \tan 60° = 19.05$ m ≈ 19.00 m

Supporting system: Container is kept 7m above the ground to keep passage for truck.
Total height = 33 + 7 = 40 m

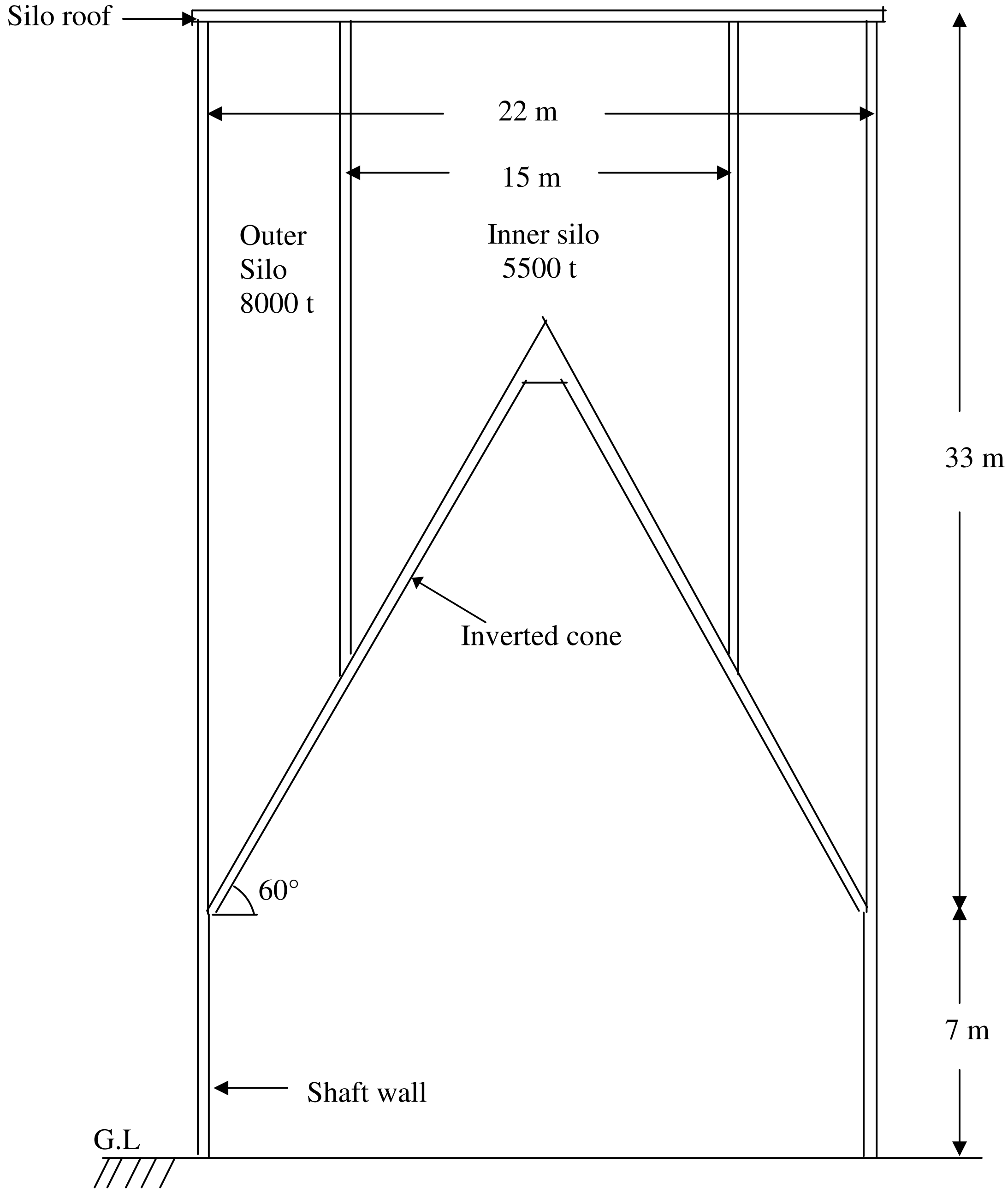


Fig 5.1 Ring silo profile

Design of silo roof:

Loads:

1. Equipment load (includes loads due to plates, conveyor support, weight of conveyor and is given by equipment supplier.) = 5 kN/m^2
2. Self weight of slab = thickness of slab×density of cement = 0.3×25 = 7.5 kN/m^2
3. Live load on slab = 1.75 kN/m^2

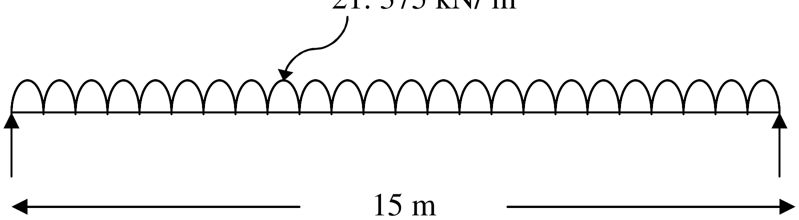
Total load = 5 + 7.5 + 1.75 = 14.25 kN/m^2

Factor load on slab = 1.5 × 14.25 = 21.375 kN/m^2

Inner silo slab design:

Diameter of inner silo = 15m

U.D.L = 21.375 kN/m^2



At center of slab:

Maximum radial moment per unit width of slab

$$Mr = 3/16 \times w \times a^2 = 3/16 \times 21.375 \times 15^2 = 225.439 \text{ kN m/m}$$

Maximum circumferential moment per unit width of slab

$$M_\theta = 3/16 \times w \times a^2 = 3/16 \times 21.375 \times 15^2 = 225.439 \text{ kN m/m}$$

At end of slab:

Maximum radial moment per unit width of slab Mr = 0

Maximum circumferential moment per unit width of slab

$$M_\theta = 2/16 \times w \times a^2 = 3/16 \times 21.375 \times 15^2 = 150.29 \text{ kN m/m}$$

Effective depth of slab is given by B.M = Rbd^2

For M_{20} and Fe 415 R= 2.76

$$225.44\times10^6 = 2.76\times1000\times d^2 ; \; d = 285.8 \text{ mm}$$

Adopt d = 300 mm and D = 320mm

Area of steel require

$$At = 0.36\times f_{ck}\times b\times Xumax / 0.87 fy = 0.36\times20\times1000\times0.48\times300/0.87\times415$$

$$= 2871.62 \text{ mm}^2$$

Minimum area of steel = 0.12%

$$= (0.12/100)\times 1000\times300 = 360 \text{ mm}^2 < At$$

So provide area of steel as At = 2871.63 mm^2

Spacing required $= \pi/4\ (d)^2 \times 1000 / At = \pi/4\ (20)^2 \times 1000 / 2871.62 = 109.39$ mm

Provide 20 mm diameter reinforcement at 100 mm c/c in the form of mesh mutually right angle to each other at a clear cover of 15 mm from bottom of slab.

Total circumferential reinforcement required at edges = $2/3 \times 2871.62 = 1914.4$ mm^2

Use 20 mm diameter reinforcement in the form of rings at 160 mm c/c spacing

Development length of 20 mm bars = $75.22 \times \phi = 75.22 \times 20 = 1504.375$ mm

2/3 of development length $= 2/3 \times 1504.375 = 1002.91$ mm

Provide 7 ring of 160mm c/c of 20 mm diameter reinforcement

Area provided by 7 rings $= \pi/4\ (20)^2 \times 7 = 2199.05$ mm^2

Check for shear:

Clear span = 15 – 0.3 = 14.7 m

Clear radius = 14.7/2 = 7.35 m

The maximum shear force occurs at supports and its value is

$1/2 \times w \times a = 1/2 \times 21.375 \times 7.35 = 78.55$ kN/m

Nominal shear stress $\tau_v = Vu / bd = 78.55 \times 1000 / 1000 \times 300 = 0.262$ N/mm^2

% tension steel = 100 At / bd

$= (100 \times \pi/4\ (20)^2 \times 1000/160) / 1000 \times 300 = 0.65$ %

Shear strength of 0.65% for M_{20} $\tau_c = 0.53$ N/mm^2

Here $\tau_v < \tau_c$ so safe in shear.

Check for development length:

Moment of resistance $M_1 = 0.87 \times fy \times At\ (d - fy \times At / fck \times b)$

$= 0.87 \times 415 \times 314.15 \times 1000/160\ (300 - 415 \times 314.15/20 \times 1000)$

= 208.05 kN m

V = 78.55 kN/m

Assuming anchorage length Lo= 0

$Ld \leq 1.3\ (M1/V) + Lo$

$72.5\ \phi \leq 1.3\ (208.05 \times 10^6 / 78.55 \times 10^3) + 0$

$\phi \leq 47.83$ mm

Here adopted diameter is 20 mm so safe

The code required that reinforcement must be taken inside simple supports by at least

$Ld / 3 = 72.5 \times 20 / 3 = 480$ mm

Outer silo slab design:

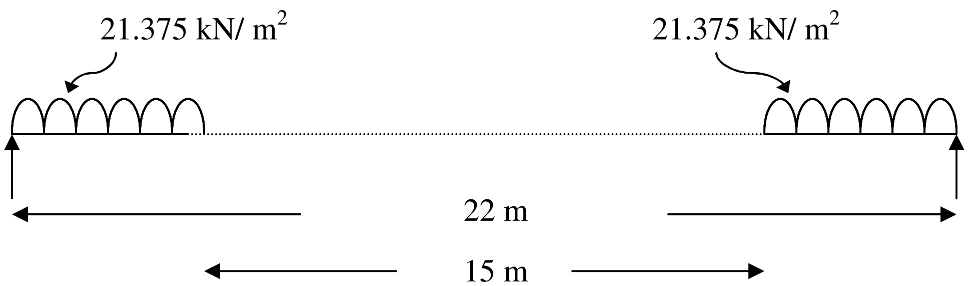
Diameter of outer silo = 22 m

Case1. Simply supported slab with central hole and uniformly distributed load

(Considering inner silo part as hole)

Case2. Simply supported slab with central hole and concentric load at hole
(Considering reaction at support of inner silo as concentric load)

Case1: Simply supported slab with central hole and uniformly distributed load
(Considering inner silo part as hole)



Radial moment Mr (kN-m /m) is given by

$$Mr = -3/16\, w\, r^2 + w\, b^2/4\, [\log_e (r/a) + ¾\, (1+ a^2/b^2 – a^2/r^2) +((a^2-r^2)/(a^2- b^2)\, (b/r)^2 \log_e(a/b)]$$

Circumferential moment M_θ(kN-m /m) is given by

$$M_\theta = -1/16\, w\, r^2 + wb^2/4[\log_e (r/a) + ¾\, (1/3+ a^2/b^2 + a^2/r^2) -((a^2-r^2)/(a^2- b^2)\, (b/r)^2 \log_e(a/b)]$$

Radial shear force V (kN) is given by

$$V = 0.5\times w\times r – 0.5\times w\times b^2/r$$

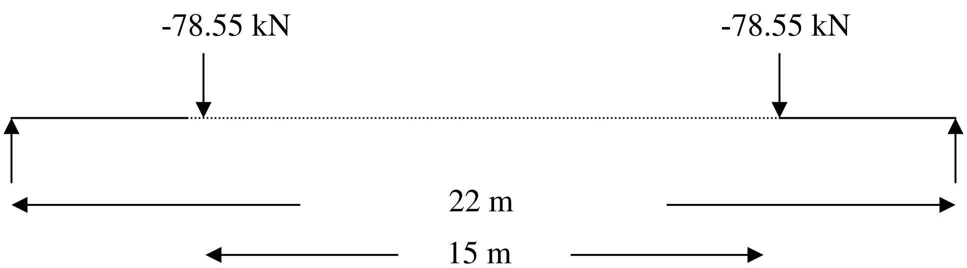
Here,

a =22 m; b =15m; w = 21.375 kN/m2

Table 5.1 Mr, M_θ, V for different r-values

r (m)	15	16	18	19	21	22
Mr (kN-m /m)	0	79.4	152.92	138.11	59.66	0
M_θ (kN-m /m)	1568.64	1473.16	1323.3	1261.4	1151.7	1100.78
V (kN)	0.17	20.87	59	76.65	110.1	125.96

Case 2. Simply supported slab with central hole and concentric load at hole
(Considering reaction at support of inner silo as concentric load)



Here,

a = 22m; b = 15m; c = 15m; w = 78.55 kN

Radial moment Mr (kN-m /m) is given by

$$Mr = P/4\pi[\log_e (c/r) - 0.5 + ((r^2 - b2)/(a^2 - b^{2)})(a / r)^2 \lambda + c^2/ 2 r^2]$$

$$\lambda = [\log_e(a / b) + 0.5 - b^2/ 2\times a^2] = [\log_e(22 /15) + 0.5 - 15^2/ 2\times 22^2] = 0.65$$

Circumferential moment M_θ(kN-m /m) is given by

$$Mr = P/4\pi[\log_e (c/r) + 0.5 + ((r^2 + b2)/(a^2 - b^{2)})(a / r)^2 \lambda - c^2/ 2 r^2]$$

Shear force V (kN) is given by

$$V = 0.5\times P/\pi r$$

Table 5.2. Mr, $M_{\theta,}$ V for different r-values

r (m)	15	16	18	19	21	22
Mr (kN-m /m) M_θ (kN-m /m) V (kN)	0 15.25 0.23	0.14 14.3 0.21	0.235 12.74 0.19	0.22 12.08 0.18	0.101 10.94 0.16	0 10.44 0.15

As force in case 2 is acting upward values in Table2 are considered as negative and net moment and shear force values are tabulated as below

Table 5.3 Net Mr, M_{θ}, V for different r-values

r (m)	15	16	18	19	21	22
Mr (kN-m /m) M_{θ} (kN-m /m) V (kN)	0 1553.39 0.06	79.26 1458.86 20.66	152.68 1310.56 58.81	137.89 1249.32 76.47	59.56 1140.76 109.94	0 1090.34 125.81

Now,

Maximum radial moment Mr = 152.68 kNm /m

Maximum circumferential moment M_{θ} = 1553.39 kNm /m

Maximum radial shear force V = 125.81 kN

Effective depth $d = \sqrt{Mu / Rb} = \sqrt{152.68 \times 10^6 / 2.76 \times 1000} = 235.19$ mm

Provided d = 300 mm o.k.

Now,

Area of steel is given by $At = 0.36\ fck\ b\ Xu_{max} / 0.87\ fy$

$= 0.36 \times 20 \times 1000 \times 0.48 \times 300 / 0.87 \times 415 = 2871.6$ mm2

Check for shear:

Nominal shear stress $\tau_v = Vu / bd = 125.81 \times 1000 / 1000 \times 300 = 0.42$ N/mm^2

% tension steel = 100 At / bd

$= (100 \times \pi/4\ (20)^2 \times 1000/160) / 1000 \times 300 = 0.65$ %

Shear strength for 0.65% for M_{20} τ_c = 0.53 N/mm^2

Here $\tau_v < \tau_c$ so safe in shear.

Silo wall design:

Lateral load calculation for silo wall [I.S. Approach]

Two condition:

- Normal filling
- Normal emptying

Pressure calculation for inner silo wall:

Hydraulic radius R = D/ 4 = 15/ 4 = 3.75 m

Density of cement w = 16 kN/m^3
Angle of wall friction while filling $\mu_f = 0.75 \times \phi \times \pi /180 = 0.75 \times 25 \times \pi /180 = 0.327$
Angle of wall friction while Emptying $\mu_e = 0.6 \times \phi \times \pi /180 = 0.6 \times 25 \times \pi /180 = 0.262$

Table 5.4 Pressure calculation [I.S. Approach]

Name of pressure	Filling condition kN/m^2	Emptying condition kN/m^2
Vertical load transferred to wall per unit area due to friction P_w	$= w \times R$ $= 16 \times 3.75$ $= 60$	$= w \times R$ $= 16 \times 3.75$ $= 60$
Horizontal pressure on silo Wall P_h	$= w \times R/ \mu_f$ $= 60/ 0.327$ $= 183.486$	$= w \times R/ \mu_e$ $= 60/ 0.262$ $= 229.0$
Vertical pressure on horizontal cross section of wall Pv	$= w \times R/ \lambda_f \mu_f$ $= 60/ 0.5 \times 0.327$ $= 366.97$	$= w \times R/ \lambda_e \mu_e$ $= 60/ 1.0 \times 0.262$ $= 229.0$

During filling $Zo_f = R / \lambda_f \mu_f = 3.75 / 0.5 \times 0.327 = 22.94$ m
During emptying $Zo_e = R / \lambda_e \mu_e = 3.75 / 1.0 \times 0.262 = 14.31$ m

$$Pi (z) = Pi_{max} (1- e^{-Z/Zo})$$

Filling condition:
Lateral pressures at different depths are calculated as follows:

$P_{10} = 183.486 (1- e^{-10/22.94}) = 64.83$ kN / m^2
$P_{14} = 183.486 (1- e^{-14/22.94}) = 83.82$ kN / m^2
$P_{20} = 183.486 (1- e^{-20/22.94}) = 106.75$ kN / m^2
$P_{25} = 183.486 (1- e^{-25/22.94}) = 121.78$ kN / m^2
$P_{26.57} = 183.486 (1- e^{-26.57/22.94}) = 106.75$ kN / m^2
$P_{30} = 183.486 (1- e^{-30/22.94}) = 133.87$ kN / m^2
$P_{33} = 183.486 (1- e^{-33/22.94}) = 139.94$ kN / m^2

Emptying condition:

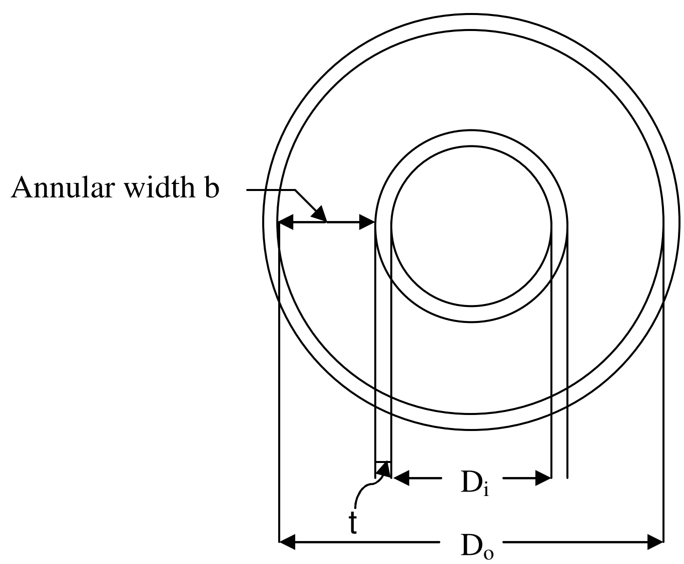
$Pi_{max} = 229.0$ kN / m^2

$P_{10} = Pi_{max} (1- e^{-Z/Zoe}) = 229 (1- e^{-10/14.31}) = 115.0$ kN / m^2
$P_{14} = 229 (1- e^{-14/14.31}) = 142.91$ kN / m^2
$P_{20} = 229 (1- e^{-20/14.31}) = 172.39$ kN / m^2
$P_{24} = 229 (1- e^{-24/14.31}) = 186.19$ kN / m^2
$P_{26} = 229 (1- e^{-26/14.31}) = 191.78$ kN / m^2
$P_{27.56} = 229 (1- e^{-27.56/14.31}) = 195.96$ kN / m^2
$P_{30} = 229 (1- e^{-30/14.31}) = 200.85$ kN / m^2
$P_{33} = 229 (1- e^{-33/14.31}) = 206.81$ kN / m^2

Table5.6 Lateral pressures at different depths by I S Approach.(Inner wall)

Depth (m)	2	6	10	18	20	24	27.56
Pressures (kN/m2)	29.87	78.43	115.0	163.90	172.39	186.19	195.96

Pressure calculation: outer silo wall



Assuming initial thickness of silo wall as 0.35 m

Annular width b = (Do – Di – t ×2)/2 = (22 – 15 – 0.35×2)/2 = 3.15 m
Hydraulic radius R = b/2 = 3.15/2 = 1.575m

During filling Zo_f = $R / \lambda_f \mu_f$ = 1.575 /0.5× 0.327 = 9.63 m
During emptying Zo_e = $R / \lambda_e \mu_e$ = 1.575 /1.0 × 0.262 = 6.01 m

Table 5.7 Pressure calculation outer silo wall:

Name of pressure	Filling condition kN/m^2	Emptying condition kN/m^2
Vertical load transferred to wall per unit area due to friction P_w	$= w \times R$ $= 16\times1.575$ $= 25.2$	$= w \times R$ $= 16\times1.575$ $= 25.2$
Horizontal pressure on silo Wall P_h	$= w \times R/ \mu_f$ $= 25.2/ 0.327$ $= 77.064$	$= w \times R/ \mu_e$ $= 25.2/ 0.262$ $= 96.18$
Vertical pressure on horizontal cross section of wall Pv	$= w \times R/ \lambda_f \mu_f$ $= 25.2/0.5\times0.33$ $=154.128$	$= w \times R/ \lambda_e \mu_e$ $= 25.2/1.0\times0.26$ $= 96.18$

Table5.8 Lateral pressures at different depths by I S Approach.(Outer wall)

Depth (m)	Pressure in Filling condition kN/m^2	Pressure in Emptying condition kN/m^2
2	14.45	27.23
5	31.21	54.32
6	35.73	60.74
10	49.78	77.96
15	60.83	88.83
18	65.17	91.37
20	67.40	92.73
24	70.68	94.40
25	71.32	94.68
27.56	72.65	95.20
30	73.64	95.52
33	74.56	95.78

NOTE: Here inverted cone is at level of 27.56m from top for outer silo so that reduction in pressure starts from that point and depends on Hydraulic radius (R)

Lateral pressure calculation as per ACI 313

Loading cases:

1. Inner silo full outer silo full
2. Inner silo full outer silo Empty
3. Inner silo empty outer silo full
4. Inner silo empty outer silo empty

Static pressure $Pz = wR/\mu\ [1 - e^{-\mu\lambda Z/R}]$

Angle of wall friction $\delta = 25°$

Co efficient of wall friction $\mu = \tan\delta = \tan 25° = 0.466$

Pressure ratio $\lambda = 1 - \sin\phi / 1 + \sin\phi = 1 - \sin 25 / 1 + \sin 25 = 0.406$

$$Pz = 16 \times 3.75/0.466\ [1 - e^{-0.466 \times 0.406 \times Z/3.75}] = 128.75[1 - e^{-0.05 \times Z}]$$

At top of cone Z = 14m

$$P_{14} = 128.75[1 - e^{-0.05 \times 14}] = 64.81\ kN/m^2$$

At top of inner ring beam Z = 27.56 m

$$P_{27.56} = 128.75[1 - e^{-0.05 \times 27.56}] = 96.329\ kN/m^2$$

At Z = 27.56m Hydraulic radius R is less than 3.75m so that pressure is much less

Outer silo wall: R = b/2 = 3.15/2 = 1.575 m

Static pressure $Pz = 16 \times 1.575/0.466\ [1 - e^{-0.466 \times 0.406 \times Z/1.575}] = 54.07[1 - e^{-0.12 \times Z}]$

At top of outer ring beam Z = 33 m

$$Pz = 54.07[1 - e^{-0.12 \times Z}] = 54.07[1 - e^{-0.12 \times 33}] = 53.04\ kN/m^2$$

Hoop reinforcement required

$$At = c_d \times p_z \times D/2 \times 1/\sigma_{sa}$$

$$\sigma_{sa} = 2100\ kg/cm^2 = 21\ kN/cm^2$$

Table 5.9 Inner silo hoop reinforcement:

Height Z(m)	p_z kN/m^2	c_d	$c_d \times p_z$	At cm^2/m	Total steel (cm^2/m) Outer face	Inner face
2	12.25	1.35	16.54	5.9	2.95	2.95
6	33.37	1.35	45.05	16.08	8.04	8.04
10	50.66	1.55	78.52	28.03	14.015	14.015
14	64.82	1.65	106.95	38.18	19.09	19.09
18	76.4	1.0	76.40	27.27	13.635	13.635
20	81.38	1.0	81.38	29.06	14.53	14.53
24	89.97	1.0	89.97	32.11	16.05	16.05
27.56	96.29	1.0	96.29	34.37	17.185	17.185

Outer silo hoop reinforcement:

$$P_z = 54.07\,[1 - e^{-0.12 \times z}]$$
$$At = c_d \times p_z \times (D/2) / \sigma_{sa}$$

Static pressure and Area of steel for outer silo wall are tabulated as follow:

Table 5.10: Hoop reinforcement for outer silo

Height Z(m)	p_z kN/m^2	c_d	$c_d \times p_z$	At cm^2/m	Total steel Outer face	Inner face
2	11.54	1.75	20.195	5.29	2.645	2.645
6	27.75	1.75	48.56	25.44	12.72	12.72
8	33.37	1.90	63.403	33.21	16.61	16.61
10	37.78	1.90	71.79	37.60	18.80	18.80
14	43.99	1.90	83.58	43.78	21.89	21.89
18	47.83	2.0	95.66	50.18	25.05	25.05
20	49.16	2.0	98.32	51.50	25.75	25.75
24	51.035	2.0	102.07	53.46	26.73	26.73
27.56	52.09	2.0	104.18	54.57	27.28	27.28
30	52.59	1.0	52.59	27.55	13.77	13.77
33	53.04	1.0	53.04	27.78	13.89	13.89

Lateral pressure calculation by Airy's method:

Coefficient of friction between cement particles $\mu = 0.466$
Coefficient of friction between cement particles and concrete wall $\mu' = 0.36$

For inner silo:
The depth up to h' up to which the bin will behave as shallow

$$h' = d\,[\mu + (\mu\,(1+\mu^2) / (\mu + \mu'))^{1/2}]$$
$$= 15\,[0.466 + (0.466(1+0.466^2) / (0.466+036))^{1/2}] = 19.41 \text{ m}$$

Lateral pressures up to h' is calculated as below

$$ph = w\times h / [\sqrt{\mu(\mu + \mu')} + \sqrt{(1+\mu^2)}\;]^2$$
$$= 16\times h / [\sqrt{0.466\,(0.466 + 0.36)} + \sqrt{(1+ 0.466^2)}]^2 = 5.38\,h$$

At h = 2 m $\quad ph = 5.38\times 2 = 10.76$ m
At h = 18m $\quad ph = 5.38\times 18 = 96.84$ m

Now, pressures below 19.41 m is calculated as below

$$ph = w\times h / (\mu + \mu')\,\{1- ((1+\mu^2)^{1/2}/\{2h/d\,(\mu + \mu') + 1- \mu\mu'\}^{1/2}\}\}$$

At h = 20 m $\quad ph = 16\times 20 / (0.466 + 0.36)\,\{1- ((1+ 0.466^2)^{1/2}/\{2\times 20/15\,(0.466 + 0.36) + 1- 0.466\times 0.36\}^{1/2}\}\}$

$$= 106.35 \text{ m}$$

At h = 27.56 m ph = 16×27.56 / (0.466 + 0.36) {1- ((1+ $0.466^2)^{1/2}$/{2×27.56/15 (0.466 + 0.36) + 1- 0.466×0.36}$^{1/2}$}}

= 27.38 m

Table 5.11 Lateral pressures for different depths

Depth (m)	2	6	10	18	20	24	27.56
Pressures (kN/m2)	10.76	32.28	53.8	96.84	106.35	118.42	127.38

For outer silo:

The depth up to h' up to which the bin will behave as shallow

$$h' = d\,[\mu + (\mu\,(1+\mu^2) / (\mu + \mu'))^{1/2}]$$

$$= 22\,[0.466 + (0.466(1+0.466^2) / (0.466+036))^{1/2}] = 28.47 \text{ m}$$

Lateral pressures up to h' is calculated as below

$$ph = w \times h / [\sqrt{\mu(\mu + \mu')} + \sqrt{(1+\mu^2)}\ ]^2$$

$$= 16 \times h / [\sqrt{0.466\,(0.466 + 0.36)} + \sqrt{(1+0.466^2)}]^2 = 5.38\ h$$

At h = 2 m   ph = 5.38× 2 = 10.76 m

At h = 18m   ph = 5.38× 18 = 96.84 m

At h = 27.56 m ph = 5.38× 27.56 = 148.27 m

Now, pressures below 28.47 m is calculated as below

$$ph = (w \times h / (\mu + \mu'))\ \{1- ((1+\mu^2)^{1/2} / \{2h/d\,(\mu + \mu') + 1- \mu\mu'\}^{1/2}\}\}$$

At h = 30 m   ph = (16×30 / (0.466 + 0.36)){1- ((1+ $0.466^2)^{1/2}$/{2×30/22(0.466 + 0.36) + 1- 0.466×0.36}$^{1/2}$}}

= 216.84 m

At h = 33 m   ph = (16×33 / (0.466 + 0.36)){1- ((1+ $0.466^2)^{1/2}$/{2×33/22(0.466 + 0.36) + 1- 0.466×0.36}$^{1/2}$}}

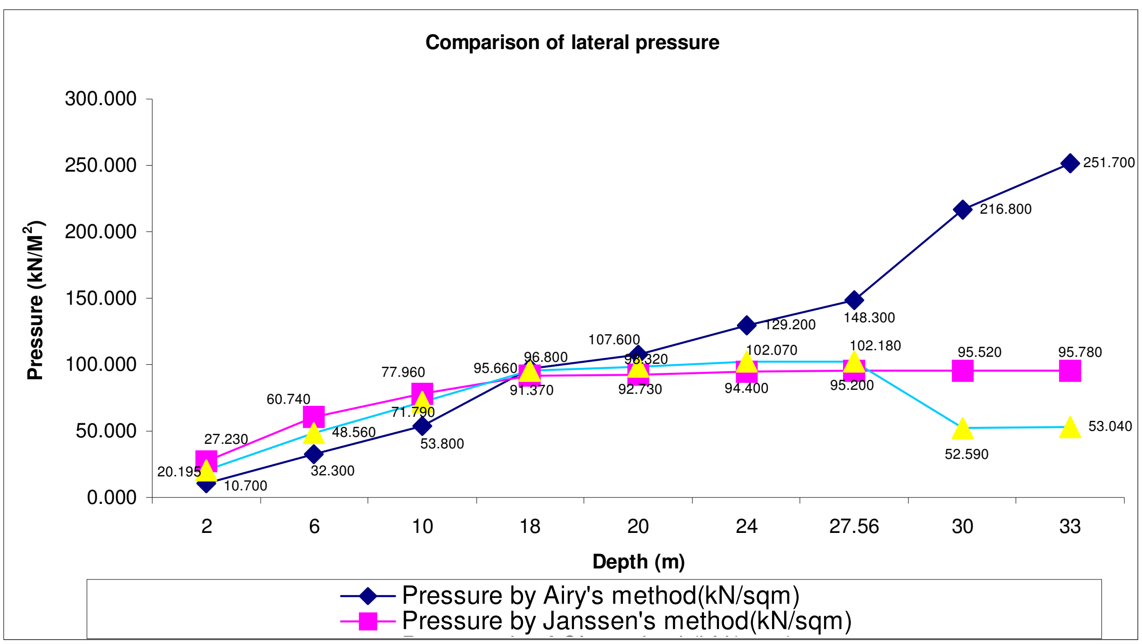
= 251.74 m

Table 5.12 Lateral pressures for different depths

Depth (m)	2	6	10	18	20	24	27.56	30	33
Pressures (kN/m2)	10.7	32.3	53.8	96.8	107.6	129. 2	148.3	216.8	251.7

Table 5.13 Comparison of lateral pressures:

Depth	Pressures by Airy's method (kN/m^2)		Pressures by Janssen's method (kN/m^2)		Pressures by ACI method (kN/m^2)	
(m)	Inner silo	Outer silo	Inner silo	Outer silo	Inner silo	Outer silo
2	10.7	10.7	29.87	27.23	16.54	20.195
6	32.3	32.3	78.43	60.74	45.05	48.56
10	53.8	53.8	115.0	77.96	78.52	71.79
18	96.8	96.8	163.90	91.37	106.95	95.66
20	106.35	107.6	172.39	92.73	76.40	98.32
24	118.42	129.2	186.19	94.40	89.97	102.07
27.56	127.38	148.3	195.96	95.20	96.29	102.18
30		216.8		95.52		52.59
33		251.7		95.78		53.04



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Frictional load on silo walls:

$$\text{Frictional load } Pw = w\,R\,[1 - e^{-\mu\,\lambda\,z/R}]$$

Equivalent fill height of inner silo = $5500/1.6\pi\times 7.5^2 = 19.45$ m
Equivalent fill height of inner silo = $8000/1.6\pi(11^2 - 7.85^2) = 26.80$ m

Inner silo

$$Pw = w\,R\,[1 - e^{-\mu\,\lambda\,z/R}] = 16\times3.75[1 - e^{-0.466\times0.41\,z/3.75}] = 60\,[1 - e^{-0.051\,z}]$$

$$\int_0^{19.45} Pw\,dz = [(60\times19.45)] - [60/(-0.051)(e^{-0.051\times19.45} - e^{0})] = 435.39 \text{ kN/m}^2$$

Pw inner = $435.39\times\pi\times15 = 20516.6$ kN ≈ 2052 tons

Outer silo

$$Pw = w\,R\,[1 - e^{-\mu\,\lambda\,z/R}] = 16\times1.575[1 - e^{-0.466\times0.41\,z/1.575}] = 25.2\,[1 - e^{-0.12\,z}]$$

$$\int_0^{26.8} Pw\,dz = [(25.2\times26.8)] - [25.2/(-0.12)(e^{-0.12\times26.8} - e^{0})] = 473.78 \text{ kN/m}^2$$

Pw inner = $473.78\times\pi\times(15 + 0.35\times2) = 23367.56$ kN ≈ 2337 tons
Pw outer = $473.78\times\pi\times 22 = 32744.35$ kN ≈ 3274 tons

Vertical friction load on outer wall = 3274 tons
Vertical friction load on inner wall = 2052 + 2337 = 4389 tons

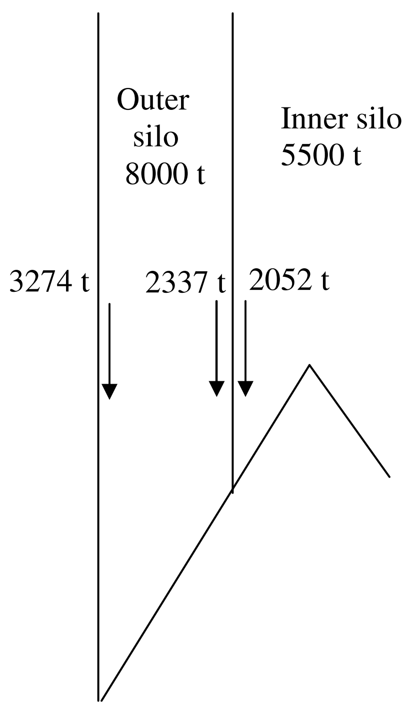

Fig.5.3 Friction loads on inner and outer silo wall

Vertical loads on walls at ledge level:

	Inner wall	Outer wall
Load from roof	3701	8695.1
Self weight Inner wall ($\pi\times15.35\times0.35$)	11269	
Self weight Outer wall ($\pi\times22.35\times0.35$)(33)(25)		20274
Load due to wall friction	43890	32740
	59220 kN	61709.1 kN
Wall area gross	$\pi\times15.35\times0.35$ $= 16.9m^2$	$\pi\times22.35\times0.35$ $= 24.6m^2$
10% opening deduction Net area	$15.2m^2$	$22.1m^2$

Permissible buckling stress = 0.25 ×fck = 0.25× 30 = 7.5 N/mm^2

Compressive stress in outer silo wall = (1.5×61709.1×1000) / 22.1×10^6 = 4.188 N/mm^2

Compressive stress in inner silo wall = (1.5×59220×1000) / 15.2×10^6 = 5.84 N/mm^2

Compressive stress is less than permissible limits so provide minimum reinforcement 0.2% = 7 cm^2/m

Check for minimum thickness of wall:

As per IS 4995 (Part II) minimum thickness of the wall can be calculated as follows

$$t_{min} = [(\eta\times Es + \sigma_{sa} - m\,\sigma_t') /100\times\sigma_{sa}\times\sigma_t']\times(Ty)_{st}$$

Where,

η = Concrete shrinkage coefficient assumed as 0.0003

Es = Modular of elasticity of reinforcing steel = 2.1×10^6 kg/cm^2

σ_{sa} = Stresses in reinforcing steel for Fe 415 [from table 2, I S 4995]

= 2100 kg/cm^2

m = Modular ratio = 9.83 for M_{30}

σ_t'= Tensile strength of concrete $=1.19\sqrt{\sigma cu}$ $=1.19\sqrt{300}$ = 20.61 kg/cm^2

$Ty_{st} = p_{hf} \times D/2$ static ring tensile force per unit length of wall at depth z

At z = 14 m p_{hf} = 64.81 kN/m^2

Ty_{st} = 64.81×15/2 = 486.075 kN/m

t_{min} = 28.48 cm

As per cl.5.5.4.1 IS 4995 the wall thickness for curved wall shall be not less than

(a) t = 10 + 2.5(D -3)/3 = 10 + 2.5(12-3)/3 = 17.5 cm

(b) t = 10+ 2.5 (h-6)/12 = 10 +2.5 (44.75 – 6)/12 = 17.05 cm

Here provided thickness is 35cm o.k.

Design of silo cone:

Here at the junction of inner silo wall and cone we get maximum results

Thickness of wall = 350 mm

Result from STAAD -PRO

Bending moment = 1.5 kNm

Axial force F = 4122 kN/m/th

Shear force Q = 153 kN/m/th

Result for design:

Bending moment = 1.5. kNm

Axial force P = 4122 × 0.35 = 1442.53 kN/m

Shear force V = 153 × 0.35 = 53.38 kN/m

Design as a column:

d'/D = 0.17

Factored axial force = P_u= 2163.8 kN/m

Factored bending moment M_u = 3.00 kNm

$P_u/f_{ck} \times b\times D$ = 0.31

$M_u/f_{ck} \times b\times D^2$ = 0.31

p/ f_{ck} = 0.0 (from SP 16 chart 34)

p % = 0.0

Minimum reinforcement required 2164 mm^2

Provide spacing = 200 mm of 16 mm diameter reinforcement

Shear design:
Effective depth of wall d = 292.00 mm
Factored shear force Vu = 80.06 kN/m
Actual shear stress τ_v = 0.27 N/mm^2
Percentage of reinforcement provided = 0.54 %
Shear strength under axial compression d = 1.5
Nominal shear strength τ_c = 0.74 N/mm^2

Here actual shear stress is less than nominal so safe in shear

Design of ring beam:

Equivalent size of ring beam
Actual area of ring beam = 1.85 m^2
Converting actual section in to a rectangular section with equivalent stiffness.
Equivalent width b = 1.1m
Equivalent depth d = 2.0 m
Here F_y = 4045 kN/m^2
Element thickness is = 0.35m

$$F_y = 0.35 \times 4045 = 1416 \text{ kN/m width}$$

Vertical force due to $F_y = F_y \sin 60 = V = 1226$ kN/m
Horizontal force due to $F_y = F_y \cos 60 = H = 709$ kN/m

These forces acts at the c.g of the beam
Offset in x- direction = x = 0.24 m
Offset in y- direction = y = 0.216m

Net moment at cg of beam = T = 141.13 kN m/m

Equivalent bending moment $M_e = T\,(1+d/b)\times 1.7 = 239$ kN m/m
Equivalent shear $V_e = 1.6\times T/b = 205.3$ kN/m

Longitudinal steel required in the beam due to bending moment

Bending stress $F_b = M_e/Z_{xx}$ = 161.86 kN/m^2
Allowable stress F_a = 210 N /mm^2
Area of steel required $= F_b\times b\times d / F_a$
= 17.55 cm^2

Longitudinal steel required in the beam due to tension
Area of steel required $= F_y \cos 60 \times R / F_a$
= 219 cm^2

Total area of steel required = 236.85 cm^2

Check for shear:

Total shear = 1431 kN/m

Nominal shear stress = 0.63 N/mm^2

P_t provided is = 1.79 %

$\tau_c = 0.48\ N/mm^2$

Here nominal shear stress is more so shear reinforcement is required.

Spacing required for 2- lagged stirrups is 276.49 mm.

Lateral load calculations and stresses in wall during Earthquake load:

According to seismic coefficient method

$\alpha_h = \beta\ I\ \alpha_0$

β = a coefficient depending upon the soil- foundation system = 1

I = a factor depending upon the importance of the structure. =1

α_0 = basic horizontal seismic coefficient depending on the different zones. = 0.08

Thus, $\alpha_h = 0.08$

Base shear $V_b = \alpha_h \times$ Total load

Calculation of horizontal seismic loads:

1. Total load on the roof slab:

   Equipment load = $5 \times (\pi/4) \times 22^2\ kN/m^2$ =1900.6 kN

   Self weight of slab = $25 \times 0.3 \times (\pi/4) \times 22^2$ = 2850.91 kN

   Total vertical load V_1 = 1900.6 + 2850.91 = 4751.52 kN

   Horizontal seismic force due to slab loading

   $H_1 = 0.08 \times 4751.52 = 380.12$ k

2. Total load of 350mm wall up to cone bottom:

   Inner silo wall = $D \times t \times h \times w_c = 15.7 \times 3.1415 \times 0.35 \times 27.56 \times 25$

   V_{2a} = 11893.9 kN

   $H_{2a} = 0.08 \times 11893.9 = 951.51$ kN

   Outer silo wall = $D \times t \times h \times w_c = 22.7 \times 3.1415 \times 0.35 \times 33 \times 25$

   V_{2a} = 20591.35 kN

   $H_{2a} = 0.08 \times 20591.35 = 1647.31$ kN

3. Total load of 600 mm (supporting system) thick wall up to top of raft:

   $= \pi \times 0.6 \times (22+0.35-06) \times 7 \times 25$

   V_3 = 7174.40 kN

   $H_3 = 7174.4 \times 0.08 = 573.95$ kN

4. Total load of hopper and ring beam:

$$\text{Volume } v_1 = 1/3\times(\pi/4)\times D^2 h = 1/3\times(\pi/4)\times 22^2 (19\text{-}1) = 2280.73 \text{ m}^3$$

$$\text{Volume } v_2 = (A_1 + A_2 + \sqrt{(A_1\times A_2)})\times h/3$$

$$A_1 = 3.14/4\ (21)^2 = 346.35 \text{ m}^2$$

$$A_2 = 3.14/4\ (1.04)^2 = 0.85 \text{ m}^2$$

$$v_2 = (346.35 + 0.85 + \sqrt{0.85\times 46.35})\times 17/3 = 2064.7 \text{ m}^3$$

Net Volume $v = 2280.73 - 2064.7 = 216.03 \text{ m}^3$

Total load of hopper = 25×216.03

$$V_{4a} = 5400.75 \text{ kN}$$

$$H_{4a} = 0.08\times 5400.75 = 432.06 \text{ kN}$$

Equivalent size of ring beam is 1.5m×2.8m (Assumed)

Self weight of ring beam = $1.5\times 2.8\times\pi\times 22\times 25$

$$V_{4b} = 7256.86 \text{ kN}$$

$$H_{4b} = 0.08\times 7256.86 = 580.55 \text{ kN}$$

5. Total load due to stored material: $V_5 = 135000$ kN

As per the provision of ACI 313 only 80% of the actual grain weight in the silo is used as an " effective weight"

$$= 0.8\times 135000 = 108000 \text{ kN}$$

Cement stored up to top of cone

$$\text{Inner silo} = (\pi/4)\times 15^2\times 14\times 16 = 39582.9 \text{ kN}$$

$$\text{Outer silo} = (\pi/4)\times(22^2 - 15^2)\times 14\times 16 = 45564.32 \text{ kN}$$

$$H5a = 0.08\times 39582.9 = 3166.63 \text{ kN}$$

$$H5b = 0.08\times 45564.32 = 3645.15 \text{ kN}$$

Cement stored in the cone area

$$\text{Inner silo} = 55000 - 39582.9 = 15417.1 \text{ kN}$$

$$\text{Outer silo} = 850000 - 45565.32 = 39435.68 \text{ kN}$$

$$H_{6c} = 15417.1\times 0.08 = 1233.37 \text{ kN}$$

$$H_{6d} = 39435.68\times 0.08 = 3154.85 \text{ kN}$$

Dead load excluding fill load DL = $V_1 + V_2 + V_3 + V_4 + V_5$

$$= 4751.52 + 11893.9 + 20591.35 + 7174.4 + 5400.75$$

$$= 49811.92 \text{ kN}$$

Live load due to fill load LL = 135000 kN

Table5.14 Earthquake load calculation:

Name	Horizontal force kN	C.G. from 0.0 level m	Moment at 0.0 level m (DL + FL)	Moment at 0.0 level m (DL)
H_1	380.12	39.85	15147.78	15147.78
H_{2a}	951.51	26.22	24948.59	24948.59
H_{2b}	1647.31	23.5	38711.78	38711.78
H_3	573.95	3.5	2008.825	2008.825
H_{4a}	432.06	13.33	5759.36	5759.36
H_{4B}	580.55	8.4	4876.62	4876.62
H_{5a}	3166.67	33	104497.8	
H_{5b}	3645.15	33	120289.95	
H_{5c}	1233.37	19.67	24260.38	
H_{5d}	3154.85	19.67	62055.89	
			Total=402556.99	91452.95

Total base shear V_b = 15765.53 kN

Total moment at 0.0 level = 402556.99 kN–m

Base shear due to only dead loads Vd = 4565.5 kN

Moment due to only dead loads at o.o level Md = 91452.95 kN-m

Load = $\pi \times 0.6 \times (22+0.35-.6) \times 4 \times 25$

V_{4b} = 4099.65 kN

H_{4b} = 4099.65 ×0.08 = 327.97 kN

Moment due to buckling of walls adjacent to openings M_b = 327.97 ×2.5 = 819.925 kN m

Geometry of wall c/s with two diametrically opposite openings:

Area of c/s of wall $A_w = 3.14/4\ (22.7^2 - 22^2) = 24.57\ m^2$

$A_o = 3 \times 0.35 + 5 \times 0.35 = 2.8\ m^2$

Net area = 21.77 m^2

Moment of Inertia @ x-x axis I_{xx}

$= (3.14/64(22.7^4 - 22^4) - (5 \times 0.6^3/12) - (3 \times 0.6^3/12) - (5 \times 0.6 \times (7/2)^2) - (3 \times 0.6 \times (7/2)^2)$

$= 1475.13\ m^4$

Moment of Inertia @ y-y axis I_{yy}

$= (3.14/64(22.7^4 – 22^4) – (5^3×0.6/12) – (3^3×0.6/12) = 1526.47\ m^4$

Section modulus @ x-x axis Zxx = $1475/\sqrt{3.5^2 – 2.5^2} = 141.07\ m^3$

Section modulus@ y-y axis Z_{yy} =1526.47/3.5 = 436.13 m^3

To compute the stresses due to local bending properties of wall on only one side are calculated

Angle of face of opening with horizontal $\alpha' = (90 – \sin^{-1}(2.5/3.5) = 44.41$

$X = R \sin \alpha'/\alpha' = 10.75 \times \sin(44.41)/0.775 = 7.83$ m

Moment of Inertia of wall on one side only @ x-x axis $I_{xx1} = 0.5 \times I_{xx} = 737.5\ m^4$

Moment of Inertia of wall on one side only @ y-y axis

$I_{yy1} = (0.5 \times I_{yy} – 0.5 \times A \times X^2)$

$= (0.5×1526.47 – 0.5 ×21.47×7.83^2) = 95.89\ m^4$

Z_{xx1} = Zxx/2 = 602.16/2 = 301.08 m^3

Z_{yy1} = 95.81/(10.75 – X) = 95.81/(10.75 – 7.83) = 32.81 m^3

Load cases:

1. DL + LL + Seismic load
2. DL + Seismic load

$F_x = (DL/A) + (LL/A) + (M/Z_{YY}) + (M_b /Z_{yy1})$

= (49811.92 + 135000)/2 + (402556.99/436.13) + (819.925/32.81)

= 56013.11 +923.02 +24.99 = 56961.12 kN/m^2

$F_x = (DL/A) + (LL/A) - (M/Z_{YY}) - (M_b /Z_{yy1})$

= (49811.92 + 135000)/2 - (402556.99/436.13) - (819.925/32.81)

= 56013.11 -923.02 -24.99 = 55065.1 kN/m^2

$F_x = (DL/A) + (M_d/Z_{YY}) + (V_d /Z_{yy1})$

= (49811.92/21.77) + (91452.95/ 436.13) + (4565.5/32.81) = 2636.99 kN

$F_x = (DL/A) - (M_d/Z_{YY}) - (V_d /Z_{yy1})$

= (49811.92/21.77) - (91452.95/ 436.13) - (4565.5/32.81) = 1939.25 kN

$F_y = (DL/A) + (LL/A) + (M/Z_{xx}) + (M_b /Z_{xx1})$

= 56013.11 + (402556.99/602.16) +(819.925/310.08) = 56684.35 kN

$F_y = (DL/A) + (LL/A) - (M/Z_{xx}) - (M_b /Z_{xx1})$

= 56013.11 - (402556.99/602.16) -(819.925/310.08) = 55341.87 kN

$F_y = (DL/A) + (M_d/Z_{xx}) + (V_d/Z_{xx1})$
$= (49811.92/21.72) + (91452.95/602.16) + (4565.5/310.08) = 2455.14$ kN

$F_y = (DL/A) - (M_d/Z_{xx}) - (V_d/Z_{xx1})$
$= (49811.92/21.72) - (91452.95/602.16) - (4565.5/310.08) = 2126.33$ kN

Maximum compressive stress = 56961.12 kN/m^2
Hence Maximum compressive load = 56961.12 × thickness = 56961.12 × 0.6
= 34176.67 kN/m

Design of shaft wall:

Load on roof including self weight = 4751.52 kN
Self weight of inner wall = 11893.9 kN
Self weight of Outer wall = 20591.35 kN
Self weight of shaft wall = $2\times\pi\times 10.7\times0.6\times7\times25 = 7058.95$ kN
Self weight of hopper and
ring beam = 5400.75+ 7256.86 = 12657.16 kN
Load due to material = 0.8×135000 = 108000 kN

Total = 165068.33 kN

Area of cross section of shaft = $2\times\pi\times 10.7\times0.6 = 40.52$ m^2
Axial stress on shaft wall = Total load/ Area
= 165068.33/40.52 = 4.0737 N/mm^2
$F_{cr} = 0.2\times(5000\sqrt{30})\times 0.6/10.7 = 305.70$ N/mm^2

Allowable buckling compressive stress $\sigma_{cr} = 0.25\times f_{ck}/(1+ f_{ck}/F_{cr})$
$= 0.25\times 30/(1+30/305.70) = 6.83$ N/mm^2

Here actual stress is less than allowable stress so nominal reinforcement is provided
$As = 0.22 \times 1000 \times 600/100 = 1320$ mm^2/m
Provide 12 mm ϕ at spacing of 100 mm c/c

Design of raft foundation:
Depth of foundation below G.L.=2.5m
Bearing capacity at 2.5 m below G.L pa = 200 kN/m^2
Total load on foundation = 165068.33 kN
Load per meter run of circumference of the girder
w = 165068.33/3.1415×22.6 = 2324.98

Maximum positive moment at center = $0.07 \times w \times r^2$

$= 0.07 \times 2324.98 \times 11.3^2 = 20781.36$

Maximum negative moment at support = $0.137 \times w \times r^2$

$= 0.137 \times 2324.98 \times 11.3^2 = 40672.1$

Maximum shear force at support = $w \times r/2 = 13136.14$ kN

Design of slab is done as per silo roof slab and final results are obtained as follows:

Radial reinforcement at center = 8600 mm^2

At r = 9 m Ast = 5011.23 mm^2

CHAPTER 6. CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

From this study several conclusions are as under:

1. Lateral pressure by ACI Approach gives more conservative results for loading case Inner silo full Outer silo empty. Indian Standard gives no guidelines for design of ring silo. Hence lateral pressures for design of silo wall are adopted as per ACI 313

2. Lateral pressure in wall is compared by various methods and results are tabulated on page 59 reveals that Airy's method gives less pressure than Janssen's method initially.

3. From the parametric study on effect of opening it is concluded that additional design pressure is higher in case of eccentric opening compared to concentric opening.

   This study shows that one can go for economical design by avoiding eccentric discharge.

   IS 4995 and ACI 313 has also suggested that as far as possible eccentric outlets should be ignored. (cl. 6.3.1, IS 4995)

4. The design of ring silo attempted manually and carried out by preparing computer programme (Appendix –I) is almost in agreement as shown in (Appendix – II)

6.2 FUTURE SCOPE

1. Parametric study considering temperature effect.

2. Design of batteries (silo group)

3. Raft foundation can be analyzed using FEM techniques because the size of foundation will be huge.

4. Prestress concrete silo can be designed for large diameter of silo for economical design.

APPENDIX - I

// PROGRAM FOR ANALYSIS AND DESIGN OF RING SILO COMPONENTS//

```
#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<stdio.h>
void main ()
{
clrscr();
float el,ts,sl,Tl,ll,Di,Mrc,Mtc,Mre,Mte,fck,fy,d,dr,
Dr,Ad,At,Atm,Atr,Dir,sp,ad,DN,tcr,spc,cs,cr,msf,nss,
pts,tc,M1,Lo,fi,Do,r,Mro,Mto,sfv,dou,MMr,sp1,spc1,Mrh,
Mth,Vh,Mnr,Mr,Mnt,Mt,Vn,w,Ri,Fi,del,l1,l2,l3,lem,z,pz,
mu,tw,Ro,l4,l5,l6,zo,z1,z2,z3,z4,z5,z6,z7,Cd,Ath,zi,Irl,
Orl,hi,Sfi,ho,Sfo,Fli,Flo,vli,vlo,Ami,Cpi,Cpo,ehi,eho,h1,
h2,h3,h4,h5,h6,h7,h8,h9,h10,pw2,Pwo1,Pwo2,pw1,Pwi,fwo,fwi,
cso,csi,Es,Ec,m,Ty,st,Tm,Arc,po,Wcr1,Wcr2,Wcr3,Wcr,Pcr,rl,
Hs,tsw,rs,hrs,ml,Cap1,Cap2,Tsl,As,xs,AS,Fr1,Fcr1,Fcr,sir;
cout<<"     PROGRAM FOR DESIGN OF SILO ROOF   "<<endl<<endl;
cout<<" give equipment load in kN/m2 as el="<<endl;
cin>>el;
cout<< "give initial thickness of slab in mm as ts="<<endl;
cin>>ts;
sl=(ts*25)/(1000.0);
cout<<" give live load on slab in kN/m3 as ll="<<endl;
cin>>ll;
Tl=1.5*(el+sl+ll);
cout<<"Tl="<<Tl<<endl;
cout<<endl<<endl;
cout<<"     INNER SILO SLAB DESIGN      "<<endl<<endl;
cout<<"give diameter of inner silo in m as Di="<<endl;
cin>>Di;
Mrc=(3.0/16)*Tl*(Di/2)*(Di/2);
```

```
Mtc=(3.0/16)*Tl*(Di/2)*(Di/2);
Mre=0;
Mte=(2.0/16)*Tl*(Di/2)*(Di/2);
cout<<" give proper grade of concrete in N/mm2 as fck="<<endl;
cin>>fck;
cout<<"give characteristic strength of steel in N/mm2 as fy ="<<endl;
cin>>fy;
d=sqrt((Mrc/(2.76*1000)));
if(d<ts)
{
dr=ts;
}
else
{
dr=d;
}
cout<<"effective depth is dr="<<dr<<endl;
cout<<" adopt proper depth considering cover as over all depth Dr="<<endl;
cin>>Dr;
ad=Dr-20;
At=(0.36*fck*1000*0.48*ad)/(0.87*fy);
Atm=1.2*ad;
if(At<Atm)
{
Atr= Atm;
}
else
{
Atr=At;
};
cout<< " Required area of steel in mm2 is Atr="<<Atr<<endl;
cout<<"give proper diameter of reinforcement in mm as Dir="<<endl;
cin>>Dir;
sp1=((3.1415/4)*1000*(Dir)*(Dir))/Atr;
cout<<"Spacing in mm as sp1="<<sp1<<endl;
cout<<"take proper spacing from this as sp="<<endl;
cin>>sp;
tcr=(2.0/3)*Atr;
```

```
spc1=((3.1415/4)*1000*(Dir)*(Dir))/tcr;
cout<<" Spacing of circumferential reinforcement in form of ring as
spc1="<<spc1<<endl<<endl;
cout<<" take proper spacing from this as sp="<<endl;
cin>>spc;
cout<<"// SHEAR CHECK FOR SLAB //"<<endl;
cs=Di-(ad/1000);
cout<<" cs ="<<cs;
cr=cs/2.0;
cout<<"cr= "<<cr;
msf=(1.0/2)*(Tl*cr);
cout<<"msf="<<msf<<endl;
nss=msf/(ad);
cout<<"nominal shear stress"<<nss<<endl;
pts=(78.54*(Dir)*(Dir)/(spc*ad));
cout<<"% tension steel ="<<pts<<endl;
cout<<" give shear strength of concrete as per I.S 456 based on % tension steel as tc
="<<endl;
cin>>tc;
if(nss<tc)
{
 cout<<"design is safe in shear"<<endl<<endl;
 }
else
{
cout<<"design is unsafe in shear"<<endl<<endl;
};
cout<<"//     CHECK FOR DEVELOPMENT LENGTH   //"<<endl<<endl;
M1=((0.87*fy*785.3*(Dir)*(Dir)/(sp))*((ad-(fy*(785.3*(Dir)*(Dir)/(sp))/(fck*1000)))));
cout<<"moment of resistace M1 in N-MM ="<<M1<<endl;
cout<<" Assume proper anchorage length in mm as Lo= "<<endl;
cin>>Lo;
fi=(((1.3*(M1/(msf*1000)))+Lo)/(72.5));
cout<<fi<<endl;
if(fi<Dir)
{
cout<<" design is unsafe in development length"<<endl;
}
```

```
else
{
cout<<"design is safe in development length"<<endl<<endl;
}
cout<<"    OUTER SILO SLAB DESIGN         "<<endl;
cout<<" give outer silo diameter as Do ="<<endl;
cin>>Do;
Do=22;
cout<< " give r "<<endl;
cin>>r;
r=15;
for(r=Di;r<=Do;r++)
{
Mro=(-(3/16)*Tl*r*r)+((Tl*Di*Di/4)*(log(r/Do))+(0.75*(1+(Do/Di)*(Do/Di)-
(Do/r)*(Do/r))+(((Do*Do-r*r)/(Do*Do-Di*Di))*((Di/r)*(Di/r))*log(Do/Di))));
Mto=(-(1/16)*Tl*r*r)+((Tl*Di*Di/4)*(log(r/Do))+(0.75*(-
1/3+(Do/Di)*(Do/Di)+(Do/r)*(Do/r))-(((Do*Do+r*r)/(Do*Do-
Di*Di))*((Di/r)*(Di/r))*log(Do/Di))));
sfv=(0.5*Tl*r)-(0.5*Tl*Di*Di/r);
Mrh=(msf/12.57)*((log(Di/r)-0.5+((r*r-Di*Di)/(Do*Do-
Di*Di))*(0.65*Do*Do/r*r)+(0.5*Di*Di/r*r)));
Mth=(msf/12.57)*((log(Di/r)+0.5+((r*r-Di*Di)/(Do*Do-Di*Di))*(0.65*Do*Do/r*r)-
(0.5*Di*Di/r*r)));
Vh=(0.16*msf)/r;
cout<<"Mro ="<<Mr<<endl;
cout<<"Mto ="<<Mto<<endl;
cout<<"sfv ="<<sfv<<endl;
cout<<"Mrh ="<<Mrh<<endl;
cout<<"Mth ="<<Mth<<endl;
cout<<"Vh ="<<Vh<<endl;
cout<<"Mr="<<Mro<<endl;
cout<<"Mt="<<Mto<<endl;
cout<<"V="<<sfv<<endl;
Mnr=Mr-Mrh;
cout<<"Mnr"<<Mnr<<endl;
Mnt=Mt-Mth;
cout<<"Mnt"<<Mnt<<endl;
Vn=sfv-Vh;
```

```
cout<<"Vn"<<Vn<<endl;
}
cout<<" from above table give maximum vlue of Mnr"<<endl;
cin>>Mnr;
dou=sqrt(Mnr*362.32);
cout<<"required depth is do ="<<dou<<endl;
At=(0.36*fck*1000*0.48*ad)/(0.87*fy);
Atm=1.2*ad;
if(At<Atm)
{
Atr= Atm;
}
else
{
Atr=At;
};
cout<< " Required area of steel in mm2 is Atr="<<Atr<<endl;
cout<<"give proper diameter of reinforcement in mm as Dir="<<endl;
cin>>Dir;
sp=((3.1415/4)*1000*(Dir)*(Dir))/Atr;
cout<<"Spacing in mm as sp="<<sp<<endl;
tcr=(2.0/3)*Atr;
spc=((3.1415/4)*1000*(Dir)*(Dir))/tcr;
cout<<" Spacing of circumferential reinforcement in form of ring as
spc="<<spc<<endl<<endl;
cout<< "      DESIGN OF SILO WALL     "<<endl<<endl;
cout<<" inner silo wall analysis"<<endl;
cout<<" give density of stored material in KN/M3 as w="<<endl;
cin>>w;
Ri=Di/4;
cout<< " give angle of internal friction of material as Fi="<<endl;
cin>>Fi;
cout<<" give angle of wall friction as del="<<endl;
cin>>del;
mu=tan(del*0.0174);
cout<< " mu= " <<mu<<endl;
lem=(1-sin(Fi*0.0174))/(1+sin(Fi*0.0174));
cout<<" lem= "<<lem<<endl;
```

```
cout<<" give depth z at top of cone in m as z="<<endl;
cin>>z;
l1=((w*Ri)/mu);
l2=-(((mu*lem)/Ri)*z);
l3=exp(l2);
pz=l1*(1-l3);
cout<<" pressure at top of cone is pz ="<<pz<<endl;
cout<<" give depth z at top of cone in m as z="<<endl;
cin>>z;
pz=l1*(1-l3);
cout<<" pressure at top of inner ring beam pz="<<pz<<endl;
cout<< " inner silo wall analysis "<<endl;
cout<<" Assume initial thickness of wall as tw in m"<<endl;
cin>>tw;
cout<<" Ri"<<Ri<<endl;
l1=((w*Ri)/mu);
cout<<" give depth z at top of inner ring beam as z= "<<endl;
cin>>zi;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z);
l3=exp(l2);
pz=l1*(1-l3)*Cd;
cout<<" pz"<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<< " give different depth z in m "<<endl;
cout<<" depth z1="<<endl;
cin>>z1;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z1);
l3=exp(l5);
pz=l1*(1-l3)*Cd;
cout<<"pz="<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z2="<<endl;
```

```
cin>>z2;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z2);
l3=exp(l2);
pz=l1*(1-l3);
cout<<"pz="<<pz<<endl;
cout<<" depth z3="<<endl;
cin>>z3;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z3);
l3=exp(l2);
pz=l1*(1-l3);
cout<<"pz="<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z4="<<endl;
cin>>z4;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z4);
l3=exp(l2);
pz=l1*(1-l3);
cout<<"pz="<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z5="<<endl;
cin>>z5;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z5);
l3=exp(l5);
pz=l1*(1-l3);
cout<<" pz"<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z6="<<endl;
```

```
cin>>z6;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z6);
l3=exp(l2);
pz=l1*(1-l3);
cout<<" pz"<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z7="<<endl;
cin>>z7;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l2=-(((mu*lem)/Ri)*z7);
l3=exp(l2);
pz=l2*(1-l3);
cout<<" pz"<<pz<<endl;
Ath=pz*(Di/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl<<endl;
cout<< " outer silo wall analysis "<<endl;
cout<<" Assume initial thickness of wall as tw in m"<<endl;
cin>>tw;
Ro=((Do-(Di+2*tw))/4.0);
cout<<" Ro"<<Ro<<endl;
l4=((w*Ro)/mu);
cout<<" give depth z at top of outer ring beam as z= "<<endl;
cin>>zo;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*zo);
l6=exp(l5);
pz=l4*(1-l6)*Cd;
cout<<" pz"<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<< " give different depth z in m "<<endl;
cout<<" depth z1="<<endl;
cin>>z1;
```

```
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z1);
l6=exp(l5);
pz=l4*(1-l6)*Cd;
cout<<"pz="<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z2="<<endl;
cin>>z2;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z2);
l6=exp(l5);
pz=l4*(1-l6);
cout<<"pz="<<pz<<endl;
cout<<" depth z3="<<endl;
cin>>z3;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z3);
l6=exp(l5);
pz=l4*(1-l6);
cout<<"pz="<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z4="<<endl;
cin>>z4;
z4=12;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z4);
l6=exp(l5);
pz=l4*(1-l6);
cout<<"pz="<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z5="<<endl;
```

```
cin>>z5;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z5);
l6=exp(l5);
pz=l4*(1-l6);
cout<<" pz"<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z6="<<endl;
cin>>z6;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z6);
l6=exp(l5);
pz=l4*(1-l6);
cout<<" pz"<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;
cout<<" depth z7="<<endl;
cin>>z7;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*z7);
l6=exp(l5);
pz=l4*(1-l6);
cout<<" pz"<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<"Ath="<<Ath<<endl;

cout<<"  VERTICAL REINFORCEMENT CALCULATION " <<endl<<endl;

cout<<" Give load from silo roof on inner wall as Irl="<<endl;
cin>>Irl;
Irl=3701;
cout<<" Give load from silo roof on outer wall as Orl="<<endl;
cin>>Orl;
cout<<" give height of inner wall as hi="<<endl;
```

```
cin>>hi;
Sfi=(Di+tw)*3.1415*tw*hi*25;
cout<<"Selfweight of inner wall"<<Sfi<<endl;
cout<<" give height of outer wall as ho="<<endl;
cin>>ho;
Sfo=(Do+tw)*3.1415*tw*ho*25;
cout<<" Self weight of outer wall"<<Sfo<<endl;
cout<< "Give capacity of inner silo in tonns as Cpi="<<endl;
cin>>Cpi;
cout<< "Give capacity of outer silo in tonns as Cpo="<<endl;
cin>>Cpo;
ehi=(Cpi/(w*0.31415*(Di/2)*(Di/2)));
cout<<"eq.height="<<ehi;
eho=(Cpo/(w*0.31415*((Do/2)*(Do/2)-((Di/2)+tw)*(Di/2+tw))));
cout<<"height2="<<eho;
h1=w*Ri;
h2=-(((mu*lem)/Ri)*ehi);
h3=exp(h2);
h4=h3-1;
h5=((h1/(-((mu*lem)/Ri)))*(h4));
pw1=((h1*ehi)-(h5));
Pwi=pw1*3.1415*Di;
//cout<<" Frictional load on inner wall is Pwi ="<<Pwi<<endl;
h6=w*Ro;
h7=-(((mu*lem)/Ro)*eho);
h8=exp(h7);
h9=h8-1;
h10=((h6/(-((mu*lem)/Ro)))*(h9));
pw2=((h6*eho)-(h10));
Pwo1=pw2*3.1415*Do;
Pwo2=pw2*3.1415*(Di+tw*2);
cout<<" Frictional load on outer wall is Pwo1 ="<<Pwo1<<endl;
cout<<" Frictional load on inner wall is Pwo2 ="<<Pwo2<<endl;
fwo=Pwo1;
fwi=Pwo2+Pwi;
cout<<" Vertical Frictional load on outer wall is fwo ="<<fwo<<endl;
cout<<" Vertical Frictional load on inner wall is fwi ="<<fwi<<endl;
vli=Sfi+Irl+fwi;
```

```
vlo=Sfo+Orl+fwo;
cout<<"Total vertical load on inner wall is vli="<<vli<<endl;
cout<<"Total vertical load on outer wall is vlo="<<vlo<<endl;
cso=((1.5*(vlo/1000))/(0.9*(3.1514*(Do+tw)*tw)));
csi=((1.5*(vli/1000))/(0.9*(3.1514*(Di+tw)*tw)));
cout<<"cso"<<cso<<endl;
cout<<"csi"<<csi<<endl;
if(cso<csi)
{
cs=csi;
}
else
{
cs=cso;
}
if(cs<7.5)
{
Ami=20000*tw;
cout<< " provide minimum reinforcement in mm2 as Ami ="<<Ami<<endl;
}
cout<<" Check for minimum thickness of silo wall"<<endl;
cout<<" Give modulus of elsticity of reinforcing steel in Kg /cm2 as Es="<<endl;
cin>>Es;
cout<<"Modulus of elasticity of concrete in Kg/cm2 as Ec="<<endl;
cin>>Ec;
m=9.39;
cout<<" Give depth of top of cone in m as z="<<endl;
cin>>z;
l1=((w*Ri)/mu);
l2=-(((mu*lem)/Ri)*z);
l3=exp(l2);
pz=l1*(1-l3);
Ty=(pz*Di/2);
cout<<"Ty="<<Ty<<endl;
st=(1.19*sqrt(fck*10));
Tm=((0.0003*Es+2100-m*st)*Ty)/(2100*st);
cout<<"Minimum thickness is Tm="<<Tm<<endl;
cout<< "CHECK FOR CRACK WIDTH BY IS METHOD "<<endl<<endl;
```

```
//cout<<" Give diameter of reinforcement for silo wall in mm as Dir="<<endl;
zo=hi;
cout<< " give  value of Cd factor as per ACI "<<endl;
cin>>Cd;
l5=-(((mu*lem)/Ro)*zo);
l6=exp(l5);
pz=l4*(1-l6)*Cd;
cout<<" pz"<<pz<<endl;
Ath=pz*(Do/2.0)*0.0476;
cout<<" Ath in  cm2/m is ="<<Ath<<endl;
Arc=100*tw;
po=Ath/Arc;
Wcr1=(6/(po* 2100))*(6/(po* 2100));
Wcr2=1-Wcr1;
Wcr3=((4+(0.005*Dir)/po));
Wcr=(0.021*Wcr3*Wcr2);
cout<<"crack width Wcr="<<Wcr<<endl;
cout<< "give permissible crack width in mm as Pcr="<<endl;
cin>>Pcr;
if(Wcr<Pcr)
{
cout<<" silo wall is safe for crak width criteria"<<endl;
}
else
{
cout<<" silo wall is unsafe so increase widh of wall "<<endl;
}
cout<<" design of shaft wall "<<endl;
rl=4751.52;
cout<<"Give height of shaft wall in m as Hs=" <<endl;
cin>>Hs;
cout<<" Give initial thickness of shaft wall in m as tsw="<<endl;
cin>>tsw;
rs=((Do-tsw)/2);
ws=(2*3.1415*25*rs*tsw*Hs);
hrs=12657.16;
ml=((Cap1+Cap2)*8);
Tsl=(rl+ws+ml);
```

```
As=(6.283*((Do-tsw)/2)*tsw);
xs=(Tsl/(1000*AS));
Fcr1=(1000*tsw*(sqrt(fck)));
Fcr=(Fcr1/((Do-tsw)/2));
cout<<" Fcr="<<endl;
sir=((0.25*fck)/(1+(fck/Fcr)));
cout<<" SIGMA CR ="<<sir<<endl;
if(xs<sir)
{
AS=(2.2*tsw);
cout<< " Area of steel  in mm as AS ="<<AS<<endl;
}
else
{
cout<< " increase thickness of slab and try again "<<endl;
}
getch();
}
```

APPENDIX - II

No	Results obtained from manual calculation	Results obtained using C++ programme
1.	SILO SLAB DESIGN: Inner silo reinforcement: Area of steel required Ast = 2871.62 mm^2 Spacing = 20 mm dia at 100 mm c /c Outer silo reinforcement Area of steel required Ast = 2871.62 mm^2 Spacing = 20 mm dia at 100 mm c /c	SILO SLAB DESIGN: Inner silo reinforcement: Area of steel required Ast = 2893.71 mm^2 Spacing = 20 mm dia at 100 mm c /c Outer silo reinforcement Area of steel required Ast = 2893.71 mm^2 Spacing = 20 mm dia at 100 mm c
2.	SILO WALL DESIGN: [ACI Method] Inner silo hoop reinforcement: At height 2.0 m hoop reinforcement = 5.9 cm^2/m At height 10 m hoop reinforcement = 28.03 cm^2/m At height 27.56 m hoop reinforcement = 34.37 cm^2/m Outer silo hoop reinforcement: At height 2.0 m hoop reinforcement = 5.29 cm^2/m At height 10 m hoop reinforcement = 37.60 cm^2/m At height 27.56 m hoop reinforcement = 54.57 cm^2/m At height 30 m hoop reinforcement = 27.55 cm^2/m At height 33 m hoop reinforcement = 27.78 cm^2/m Vertical reinforcement: Minimum reinforcement 0.2% = 7 cm^2/m Check for minimum thickness: Minimum thickness = 28.48 cm	SILO WALL DESIGN: [ACI Method] Inner silo hoop reinforcement: At height 2.0 m hoop reinforcement = 5.90 cm^2/m At height 10 m hoop reinforcement = 28.032 cm^2/m At height 27.56 m hoop reinforcement = 34.374 cm^2/m Outer silo hoop reinforcement: At height 2.0 m hoop reinforcement = 5.29 cm^2/m At height 10 m hoop reinforcement = 37.63 cm^2/m At height 27.56 m hoop reinforcement = 54.62 cm^2/m At height 30 m hoop reinforcement = 27.56 cm^2/m At height 33 m hoop reinforcement = 27.82 cm^2/m Vertical reinforcement: Minimum reinforcement 0.2% = 7 cm^2/m Check for minimum thickness: Minimum thickness = 27.96 cm

3.	DESIGN OF SILO CONE: Minimum reinforcement required 2164 mm^2 Provide spacing = 200 mm of 16 mm diameter reinforcement	DESIGN OF SILO CONE: Minimum reinforcement required 2164.0 mm^2 Provide spacing = 200 mm of 16 mm diameter reinforcement
4.	DESIGN OF RING BEAM: Total area of steel required = 236.85cm^2 Spacing required for 2- lagged stirrups is 270.00 mm.	DESIGN OF RING BEAM: Total area of steel required = 243.93 cm^2 Spacing required for 2- lagged stirrups is 276.49 $\approx$ 270.00 mm.
5.	DESIGN OF SHAFT WALL: Here actual stress is less than allowable stress so nominal reinforcement is provided As = 1320 mm^2/m Provide 12 mm ϕ at spacing of 100 mm c/c	DESIGN OF SHAFT WALL Nominal reinforcement is provided As = 1320.0 mm^2/m Provide 12 mm ϕ at spacing of 100 mm c/c

APPENDIX – III

Detailed drawings of ring silo components are attached as under:

1. Silo wall
2. Section through cone wall
3. Part plan showing top reinforcement of cone
4. Cross section of ring beam
5. Section at ring beam level
6. Section through raft

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