Certificate

Department of Civil Engineering,
School of Engineering and Technology
Anjuman-I-Islam's Kalsekar Technical Campus
Plot No. 2 3, Sector – 16, Near Thana Naka, Khanda Gaon,
New Panvel, Navi Mumbai. 410206.

This is to certify that the project entitled "**Comparative Study Of Design Aspects And Construction Practices Of Silos**" is a bonafide work of "Khan Mohd. Farhan Mohd. Aslam (14CE29), Niyazi Aftab Irshad Ahmed (14CE42), Shaikh Ahteshaam Imtiyazali (14CE51), Shaikh Saif Aslam (14CE56), submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Bachelor of Engineering" in Department of Civil Engineering.

Dr. Abdul Razak Honnutagi
Guide

Dr. Rajendra Magar
HOD

Dr. Abdul Razak Honnutagi
Director

APPROVAL SHEET

This dissertation report entitled **"Comparative Study of Design Aspect and Construction Practices of Silos"** by Khan Mohd Farhan Mohd Aslam (14CE29), Niyazi Aftab Irshad (14CE42), Shaikh Aehteshaam Imtiyazali (14CE51), Shaikh Saif Aslam (14CE56), is approved for the degree of Civil Engineering.

Examiners

1. …………………………
2. …………………………

Supervisors:

1. …………………………
2. …………………………

Date: 04/05/2018

Place: New Panvel

DECLARATION

We declare that this written submission represents our ideas in our own words and where others ideas or words have been included; we have adequately cited and referenced the original sources. We also declare that, we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Khan Mohd Farhan Mohd Aslam …………..
14CE29

Niyazi Aftab Irshad Ahmed …………..
14CE42

Shaikh Aehteshaam Imtiyazali …………..
14CE51

Shaikh Saif Aslam …………..
14CE56

Date: 04/05/2018

ABSTRACT

Silo is the term applied commonly to a structure in which dry granular materials are stored. Silos are those structures in which the height of the container is large as compared to its diameter so that the plane of rupture cuts the opposite side and does not cut the top horizontal surface. Silos are used in a wide range of industries, such as agriculture, mining, chemical engineering, power plants, cement and food processing, where most bulk solids storage, handling and transportation systems are applied for storing solid materials like grains, coal, cement etc. When bulk solids are allowed to flow out of a bin or hopper under gravity alone, its flow pattern can be basically of two types: mass flow or funnel flow. With mass flow, the hopper is sufficiently steep and smooth to cause flow of all the solids in the bin without ‘dead’ regions occurring during discharge, funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls or when the outlet of a bin is not fully effective, due to poor feeder or outlet design. From the view point of processing, mass flow is preferred in making the bulk solids processing system efficient, reliable, predictable and more easily controlled. The flow of solid particles from mass flow bins or mass flow hoppers is, therefore, a subject of considerable practical and theoretical interest.

In this project, a comparative study has been carried out on the design of silos by Indian Standard (IS) and applying rational method to provide a good hopper. In addition, schedule bar bending and cost estimation has been prepared for various heights of silos for better optimisation and economy.

Keywords—Silos, funnel flow, mass flow, bulk solids, Indian Standard

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abbreviation, Notation And Nomenclature

- P_h = Lateral bin wall pressure
- w = Specific weight of stored material
- r = Hydraulic radius of storage structure
- μ = Coefficient of friction of stored material
- k = Pressure ratio
- K_f = Pressure ratio during filling
- K_e = Pressure ratio during emptying
- Q_p = Flow rate of bulk solid
- ρ = Bulk density of particles
- D_0 = Outlet diameter of the hopper
- D = Diameter of verticle section of bin
- g = Gravitational acceleration
- ff = Flow factor for converging channel
- ff_a =Actual flow factor for a flow situation
- h = Height of hopper
- α = Hopper angle from verticle axis
- Φ = Internal angle of friction
- CAS = Critical applied stress
- MFF = Mass flow function
- b = in to in distance b/w two surfaces
- T_m = Tension along circumference in hopper
- T = Hoop tension
- W = Total live load per perimeter
- σ_h = Horizontal pressure
- σ_v = Vertical pressure
- σ_w = Pressure on wall
- t = Thickness of wall
- D = Diameter of silo
- H = Height of cylindrical portion

- A_{st} = Area of steel
- A_{sh} = Area of steel for hoop tension
- σ_{st} = Permissible direct tension on steel
- p_n = Normal pressure on hopper wall
- p_h = Horizontal pressure on hopper wall
- p_v = Vertical pressure on hopper wall
- P_w = Vertical load of grains
- A_1= Inlet area of hopper
- A_2= Oulet area of hopper

Chapter 1

Introduction

1.1 General

Silo is the term applied commonly to a structure in which dry granular materials are stored. Such structures, which are generally elevated above the ground, may be rectangular or circular in plan and may comprise one or more compartments. Generally, containers used for the storage of wheat, cement, coal, etc. are known as bunkers and silos. The essential difference between silos and bunkers lies in the ratio of their dimension, i.e., ratio of height to diameter, which governs the design of these structures. A shallow container whose diameter is large as compared to height is termed a bunker. In such structures, the plane of rupture between the wedge, which causes maximum pressure, and remaining fill cuts the top horizontal surface, and it does not cut the opposite side of the bunker. On the other hand, if the height of the container is large as compared to its diameter so that the plane of rupture cuts the opposite and does not cut the top horizontal surface, the container is termed a silo.

Silos are used in a wide range of industries, such as agriculture, mining, chemical engineering, power plants, cement and food processing, where most bulk solids storage, handling and transportation systems are applied.

Figure 1-1 Silo

One of the most important requirements is that the material should discharge smoothly and continuously when the outlet is opened. One practical problem involved in designing the handling systems for particulate materials is the attainment or an adequate flow of material and the control of the flow at some desired rate.

When bulk solids are allowed to flow out of a bin or hopper under gravity alone, its flow pattern can be of two types: mass flow or funnel flow. With mass flow, the hopper is sufficiently steep and smooth to cause flow of all the solids in the bin without ‘dead’ regions occurring during discharge. By contrast, funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls or when the outlet of a bin is not fully effective, due to poor feeder or gate design. The bulk solids flow toward the outlet through a vertical channel that forms within stagnant material powders. From the view point of processing, mass flow is preferred in making the bulk solids processing system efficient, reliable, predictable and more easily controlled. The flow of solid particles from mass flow bins or mass flow hoppers is, therefore, a subject of considerable practical and theoretical interest.

The theory of flow of bulk solids and the design of storage bins and channels for flow were the subject of studies by Andrew W. Jenike, first on his own (1952-1955), then at the Utah Engineering Experiment Station, University of Utah (1956-1962). The work led to the postulation of a flow - no flow criterion and of flow properties of solids and of channels. It will be useful to consider the typical flow patterns of bulk solids in gravity flow and to define the terminology. Since relatively new concepts, such as "flow ability of bulk solids" are used, it will be necessary not only to redefine some of the existing terms with greater precision but also to introduce new terms.

1.2 Problem Statement

Most of the engineers designing solids handling equipment do not have any formal education in the area, because it is generally ignored as an academic subject in most college and university courses. Only a handful of universities around the world offer a course in bulk solids handling, even though most manufactured goods incorporate powders. Consequently, most engineers working in this area remain unaware that there is a sound method available for hopper design. (Solids Notes 10, George G. Chase, The University of Akron).

Most of the hopper design results in undesirable discharge which leads to wastage of material on the side walls and formation of rat holes which ultimately results in failure of structure.

1.3 Proposed Solution

Designing of silos by use of rational method, proposed by Jenike, “Storage And Flow Solids” **(Section 3.6)** which mostly depends upon hopper angle, hopper outlet diameter and flow properties of solids, which is generally ignored while constructing and designing of Silos, hence it will give an proper and accurate approach for for designing and constructing of silos. Therefore, it will lead to efficient flow and increase life of structure.

1.4 Objectives of the Project

The objectives of this project are:

i) To determine hopper outlet diameter and hopper slope according to the flow properties of the bulk solid to be stored.

ii) To design silos using IS 4995: Part 1&2 (1974) for various H/D ratio as per volume requirement.

iii) To determine the quantities and cost of the materials required and

iv) To conlude the most economical design of silos for a given H/D ratio

Chapter 2

Literature Review

2.1 Introduction to Literature Review

We have referred various literatures from textbooks as well as technical and research papers from many national and international journals. Summaries of ten of the most relevant literatures are documented in the section below.

2.2 Summaries of Relevant Literature

Janssen's theory (1895)[12] is widely accepted to predict lateral wall bin pressure. According to Janssen's theory, it is assumed that a large portion of the weight of material is supported by friction between material and wall and small portion are carried to hopper bottom. Janssen's gives the following equation,

$$P_h = \frac{wR}{\mu}\left(1 - \exp\left(\frac{-\mu K h}{R}\right)\right)$$

Airy’s theory (1897)[1] presented a more complex equation to calculate horizontal pressure on bin walls. The pressure predicted by both the theories gives quite similar results. Due to the complexity of this theory, Janssens’s theory is mostly used.

Newton et. al.(1945)[2] studying the flow of catalyst pellets (2.54 - 5.08 mm in diameter), proposed that the flow rate varied with the orifice diameter and the height or material level. The authors found orifice blocking when the orifice diameter was less than six times the mean particle diameter.

Franklin and Johanson (1955)[3] studied the flow of such granules as glass beads; lead shot and puffed rice with particle diameter of 0.787—5.207 mm discharging from a cylindrical bin with an outlet varying in size from 6.6 to 34 (particles diameter). They correlated discharge rate with orifice diameter, particle diameter, particle density and material friction. They reported no influence of material level on the flow rates observed.

Fowler and Glastonbury (1959)[4] scrutinized the effects of changing orifice shape for discharge from flat bottomed bins. Materials of particle size ranging from 270 µm to 3300 µm were tested. They found that flow rate was related to hydraulic diameter of the orifice, mean particle size and shape factor for the material; the effect of material head was found to be negligible.

Jenike (1964)[5] provide the engineers with enough information to enable him to design storage plants and flow channels and unobstructed flow. A simplified method of measuring the flow-function of a solid has been introduced. This method saves a great deal of time in separating free-flowing from non-free-flowing solids, and in intricate testing problems

Johanson’s method (1965)[6] involves the determination of the critical flow factor for arching of and the actual flow factor for the material under dynamic conditions which are related to the flow properties or bulk solids and hopper geometry, it gives a good prediction of the flow rate for coarse cohesive material.

Experiments carried out by Johanson using several different bulk solids in both laboratory and field tests, supported his theory. However, he found the experimental discrepancies to be larger for finer materials, where the effect or the negative air pressure gradient becomes more significant. Therefore, equation is not able to predict the flow rate for fine material.

$$Q_p = \rho D_0^{2.5} \frac{\pi}{8} \left(\frac{g}{tan\alpha} \left(1 - \frac{ff}{ff_a} \right) \right)^{1/2}$$

Bosley et. al. (1969)[7] examined, in a photographic study, the effects of hopper shape, particle size, and particle density and hopper size on velocity profiles in hopper discharge. In their investigations, only coarse particles (1-2.5 mm in particle size) were used to eliminate the effect of air pressure gradients. The velocity profiles were found to depend primarily on hopper shape. They claimed that maximum velocities agreed reasonably well with Brown's theoretical values but a significant effect due to wall friction was observed.

E.J Benink (1989)[11], carried out Research to examine the flow behaviour and wall pressures of cohesion less bulk materials. Besides the two well-known flow types (mass flow and funnel flow), a third flow type has been observed. This type is characterized by a change of the flow behaviour if the material in cylinder drops below a critical level. Various wall pressure theories have been treated and compared with experimental results. A new theory, referred to as the arc theory, has been developed to predict the hopper wall pressures during discharge. The experiments indicate stochastic stress behaviour. The wall pressures strongly depend on the flow behaviour. A comparison between the most-used codes and the experiments have been made. Besides a critical analysis of the existing foreign codes, recommendations are given for a new silo regulation. A computer program has been developed to design a theoretical optimum silo for each bulk material.

Dietmer Schulze (2006)[17] stated that 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.

2.3 Conclusion

From this study, we can conclude that flow in hopper mainly depends upon the hopper angle, hopper outlet diameter and flow properties of the material. To design an efficient flow hopper, it is essential to select proper parameters. We can determine a proper hopper outlet diameter and hopper angle by using Jenike's rational procedure and charts mentioned in "Flow and Storage Of Bulk Solids" **(section 3.6)**.

Chapter 3

Methodology

3.1 General

Before discussing loads and structural implications on silo structures, it is important to understand the behaviour of bulk solids in storage vessels. There are two primary flow patterns that a silo can develop during discharge they are:

A) Funnel Flow

B) Mass Flow

3.1.1 Funnel Flow

In funnel flow, an active flow channel forms above the hopper outlet with stagnant material at the periphery. As the level of material in the silo decreases, material from stagnant regions may or may not slide into the flowing channel, depending on the cohesive strength of the bulk solid. When this strength is sufficient, the stagnant material does not slide into the flow channel, which results in the formation of a stable empty vertical or near vertical channel commonly known as a rat hole.

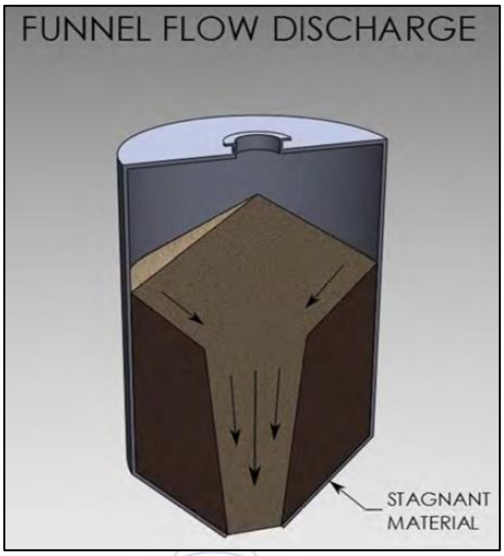


Figure 3-1 Funnel flow

In addition to flow stoppages that occur because of rat holing, funnel flow can cause material degradation, results in a first-in-last-out flow sequence, and increases the extent to which segregation affects the uniformity of the discharging material. Generally, funnel flow occurs when the hopper angles are shallow and the friction between the stored material and hopper walls is high. Funnel flow can also occur if protrusions into the flow channel are present. These protrusions could be due to horizontal welds, incorrectly lapped liner plates, or poorly constructed mating flanges as well as gates or valves not operated fully open

3.1.2 Mass Flow

In mass flow, all of the material is in motion whenever any is withdrawn from the hopper section. Material from the centre as well as the periphery moves toward the outlet, though not necessarily at the same velocity. Mass flow hoppers provide a first-in-first-out flow sequence, eliminate stagnant material, reduce segregation, and provide a steady discharge with a consistent bulk density and a flow that is uniform and well controlled. Requirements for achieving mass flow include sizing the outlet large enough to prevent arching and ensuring the hopper has sufficiently low wall (material/surface boundary) friction and steep enough walls to achieve flow at the walls. A proven, practical approach to achieving mass flow is outlined in Dr. Andrew Jenike’s work presented in Bulletin 123 [Jenike, 1994].

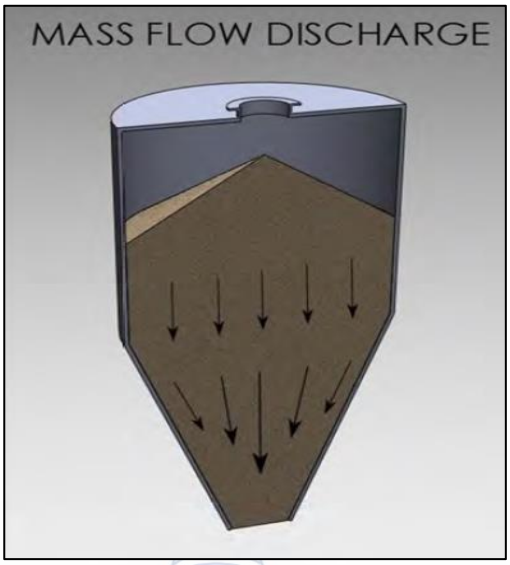


Figure 3-2 Mass flow

3.2 Flow Problems

1) Rat Holing: Rat holing or piping occurs when the core of the hopper discharges (as in funnel flow) but the stagnant sides are stable enough to remain in place without flowing, leaving a hole down through the centre of the solids stored in the bin.

2) Flow Is Too Slow: The material does not exit from the hopper fast enough to feed follow on processes.

3) No Flow Due To Arching or Doming: The material is cohesive enough that the particles form arch bridges or domes that hold overburden material in place and stop the flow completely

4) Flushing: Flushing occurs when the material is not cohesive enough to form a stable dome, but strong enough that the material discharge rate slows down while air tries to penetrate into the packed material to loosen up some of the material. The resulting effect is a sluggish flow of solids as the air penetrates in a short distance freeing a layer of material and the process starts over with the air penetrating into the freshly exposed surface of material

5) Incomplete Emptying: Dead spaces in the bin can prevent a bin from complete discharge of the material.

6) Segregation: Different size and density particles tend to segregate due to vibrations and a percolation action of the smaller particles moving through the void space between the larger particles.

7) Time Consolidation: For many materials, if allowed to sit in a hopper over a long period the particles tend to rearrange themselves hence, they become more tightly packed together. This effect is referred as Dense Packing as shown in the figure. The consolidated materials are more difficult to flow and tend to bridge or rat hole.

8) Caking: It refers to the physiochemical bonding between particles that occur due to changes in humidity. Moisture in the air can react with or dissolve some solid materials such as cement and salt. When the air humidity changes the dissolved solids re-solidify and can cause particles to grow together.

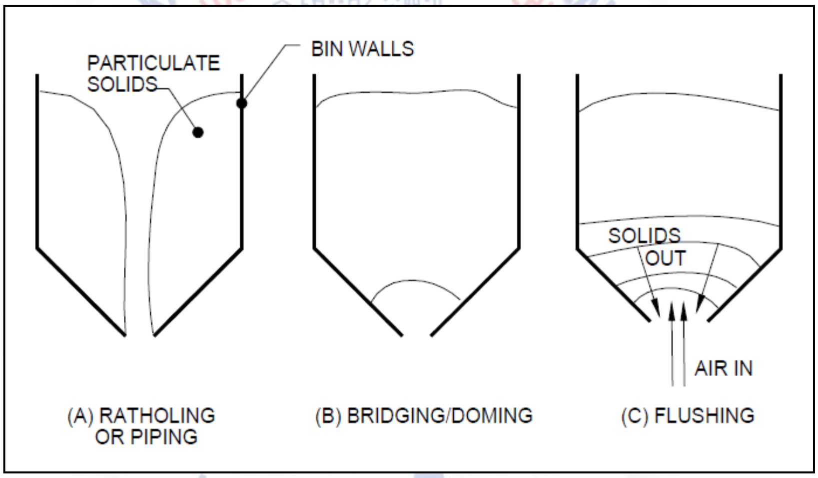


Figure 3-3 Flow problems

3.3 Flow ability of Bulk Solid and of Channel

3.3.1 Angle of repose

When an unconsolidated (loose) bulk solid deposited on a horizontal surface to form a pile, and the velocity of the stream onto the top of the pile is negligible, the particles of the solid roll down the pile and the slope of the pile forms an angle of repose with the horizontal. The angle of repose assumes values between 30^0 and 40^0 and is not a measure of the flow ability of solids. In fact, it is only useful in the determination of the contour of a pile, and its popularity among engineers and investigators is due not to its usefulness but to the ease with which it is measured**.**

If a solid contains a wide range of particle sizes, it segregates the fines collect along the trajectory of the charged solid while the coarse fraction rolls to the periphery of the pile. When the solid drops onto a pile from some height, the fines along the trajectory pack under the Impact of the larger particles, gain strength, and form a slope angle steeper than the angle of repose. If a fine powder or a flaky solid drops from a height, it aerates and spreads at an angle smaller than the angle of repose

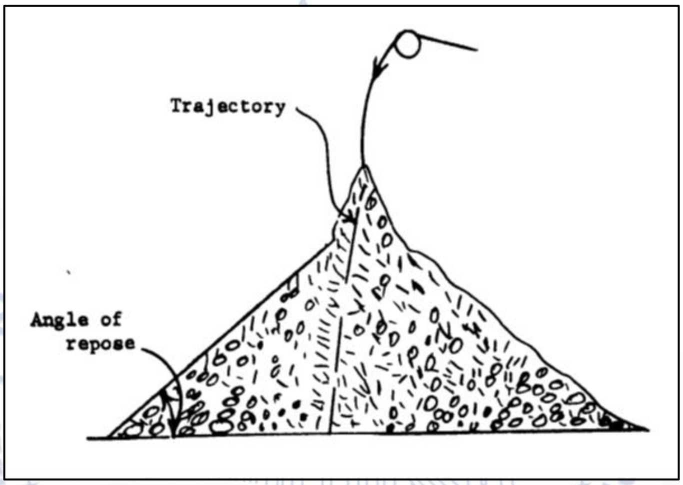


Figure 3-4 Angle of Repose

3.3.2 Effective area of an outlet

It is necessary to differentiate between the physical size of an outlet of a pile, bin, or hopper, and its effective area because, in the development of a flow pattern of a solid within the pile or bin, it is the effective area, which is significant. The effective area of an outlet is that part of the total area through which the solid actually flows when the feeder is in operation or the gate is open. It is Important to realize that in many cases the effective area forms only a part, sometimes a small part, of the total outlet.

3.3.3 Comparison of solids and liquids

The word-"flow" is more often associated with fluids than with solids, and when the "flow of solids" is mentioned, one is inclined to assume - by association - that the solid will behave much like a liquid. Such an assumption is incorrect. The properties of solids and of liquids differ so much that the mechanisms of flow of these phases are different. First, solids can transfer shearing stresses under static conditions - they have a static angle of friction greater than zero - whereas liquids do not. This is why solids form piles whereas liquids form level surfaces. Secondly, many solids, when consolidated - that is after pressure has been applied to them, possess cohesive strength and retain a shape under load. They can form a stable dome or a stable well; liquids cannot do that. Thirdly, the shearing stresses which occur in a slowly deforming (i.e. a flowing) bulk solid can usually be considered Independent of the rate of shear and dependent on the mean pressure acting within the solid. In a liquid, the situation is reversed, the shearing stresses are dependent on the rate of shear and Independent of the mean pressure.

3.3.4 Internal Angle of Friction

Soil friction angle is a shear strength parameter of soils. Its definition is derived from the Mohr-Coulomb failure criterion and it is used to describe the friction shear resistance of soils together with the normal effective stress. In the stress plane of Shear stress-effective normal stress, the soil friction angle is the angle of inclination with respect to the horizontal axis of the Mohr-Coulomb shear resistance line.

3.3.5 Bulk Density

Bulk density, or dry bulk density, is a property of soils and other masses of particulate material. It is the weight of the particles of the solid divided by the total volume. Thus, it should be noted that the unit of bulk density is the unit of weight over the unit of volume, for example kg/m3 for the metric system and lb/ft3 for the English system.

3.3.6 Cohesive Strength

Cohesion is the action or property of like molecules sticking together, being mutually attractive.

3.3.7 Optimum Water Content

The Optimum Water Content of soil is the water content at which a maximum dry unit weight can be achieved after a given compaction effort. The OWC is the water content of the soil in which you could compact it the most. If there were too much water, you would have too much pore water pressure during compression to compact any further. If there were, too little water the soil would naturally resist compaction via shear strength/friction/effective stress. The determination of the OPT is important because if tillage is carried out on fields that are wetter or drier than the OPT many problems can be caused, including soil structural damage, through the production of large clods, and an increase in the content of readily dispersible clay which is indicative of the soil stability.

3.3.8 Flow Factor

The forces acting on the powdered material stored in a hopper tend to - compact the powder (i.e., reduce its bulk density), and the shear stresses in the material tend to make it flow. Jenike (A.W. Jenike, Storage and Flow of Solids, Bulletin No. 123, Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, 1964) showed that for an element at any position inside of a mass flow hopper, the ratio of the compacting stress to the shear stress has a constant value that he called the flow factor.

$$flowfactor,(ff)=\frac{compactivestress}{appliedstress}$$

3.4 Stresses

The knowledge of the stresses prevailing in bulk solids, especially when being stored in bins and silos, is extremely important when considering the following topics:

- Silo design for flow (e.g., design procedure according to Jenike)
- Load assumptions for structural silo design.
- Loads on feeders and inserts.
- Limitation of stresses acting in a bulk solid.(e.g., to avoid particle damage)

3.4.1 Ratio of horizontal to vertical stress

The following figure shows an element of bulk solid in a cylinder, which is filled, with bulk solid (frictionless walls). The element of bulk solid is affected by the vertical stress σ_v. Because of the vertical stress, the horizontal stress σ_h acts in the horizontal direction. The stress ratio K that is well known from soil mechanics is used for the description of the ratio of σ_h to σ_v

$K = \sigma_h / \sigma_v$

Every bulk solid has a specific stress ratio K. While an ideal, non-elastic solid has a stress ratio of zero, a fluid would have a stress ratio of one. That of bulk solids stored at rest is mostly in the range from 0.3 to 0.6.

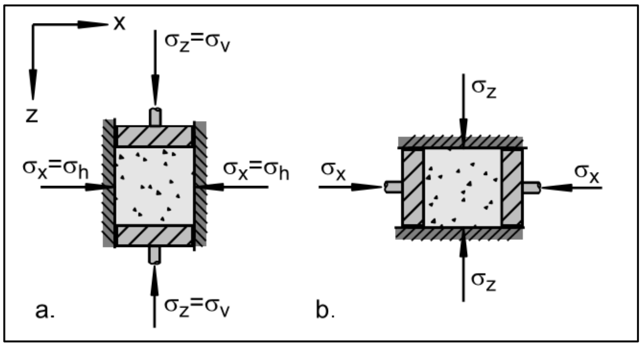


Figure 3-5 Element of Bulk Solid

3.4.2 Pressures in fluids and stresses in bulk solids

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), 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.

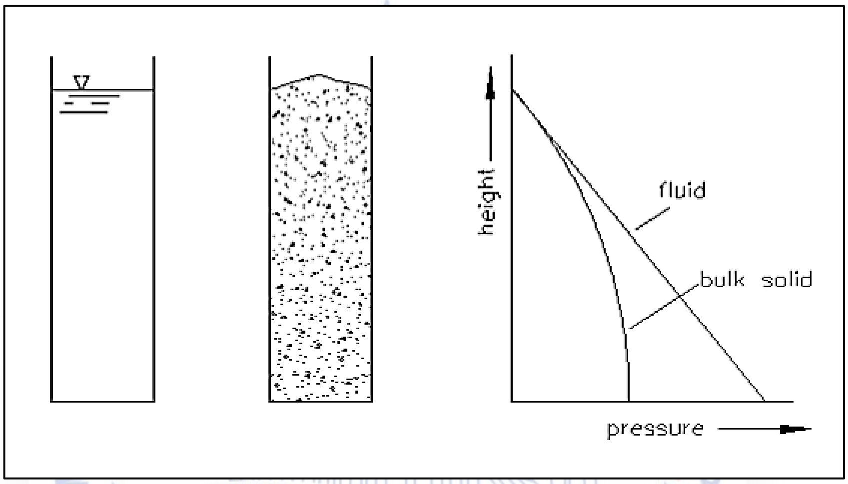


Figure 3-6 Pressures in fluids and stresses in bulk solids

3.4.3 Stresses in silos

A typical silo consists of a vertical section and a hopper. The stress conditions in the hopper are more complex than in the vertical section. If a previously empty silo is filled with a bulk solid, a stress distribution results as shown in (Fig.3-7-a). In the vertical section, both wall normal stress σ_W and the mean vertical stress σ_V are increasing in the downward direction and tend to approach an asymptotic value. The ratio of the wall normal stress to mean vertical stress is given by the lateral stress ratio K. The major principal stress (σ_1) is oriented vertically along the silo axis and deviates more and more from vertical towards the silo walls. This state of stress is called as “active state of stress” or “active stress field”.

At the transition to the hopper, the wall normal stress has a discontinuity caused by the sudden change of wall inclination. Further, downwards in the hopper, both the vertical stress and the wall normal stress are decreasing and approach zero at the hopper apex (the outlet is assumed as infinitely small), but depending on the vertical stress at the transition, the silo shape and the bulk solid's properties, the stresses in the hopper either increase in the first instance and then decrease or decrease continuously from the transition to the apex as in (Fig.3-7-a) (the stress distributions plotted in (Fig.3-7) shall be regarded as qualitative examples). In general, the stresses in vertical direction are larger than those in horizontal direction. Along the hopper axis the major principal stress is oriented vertically, i.e., an active state of stress (active stress field) prevails as in the vertical section. The stress field in the hopper prevailing after filling is also referred as "filling state of stress" or just "filling conditions".

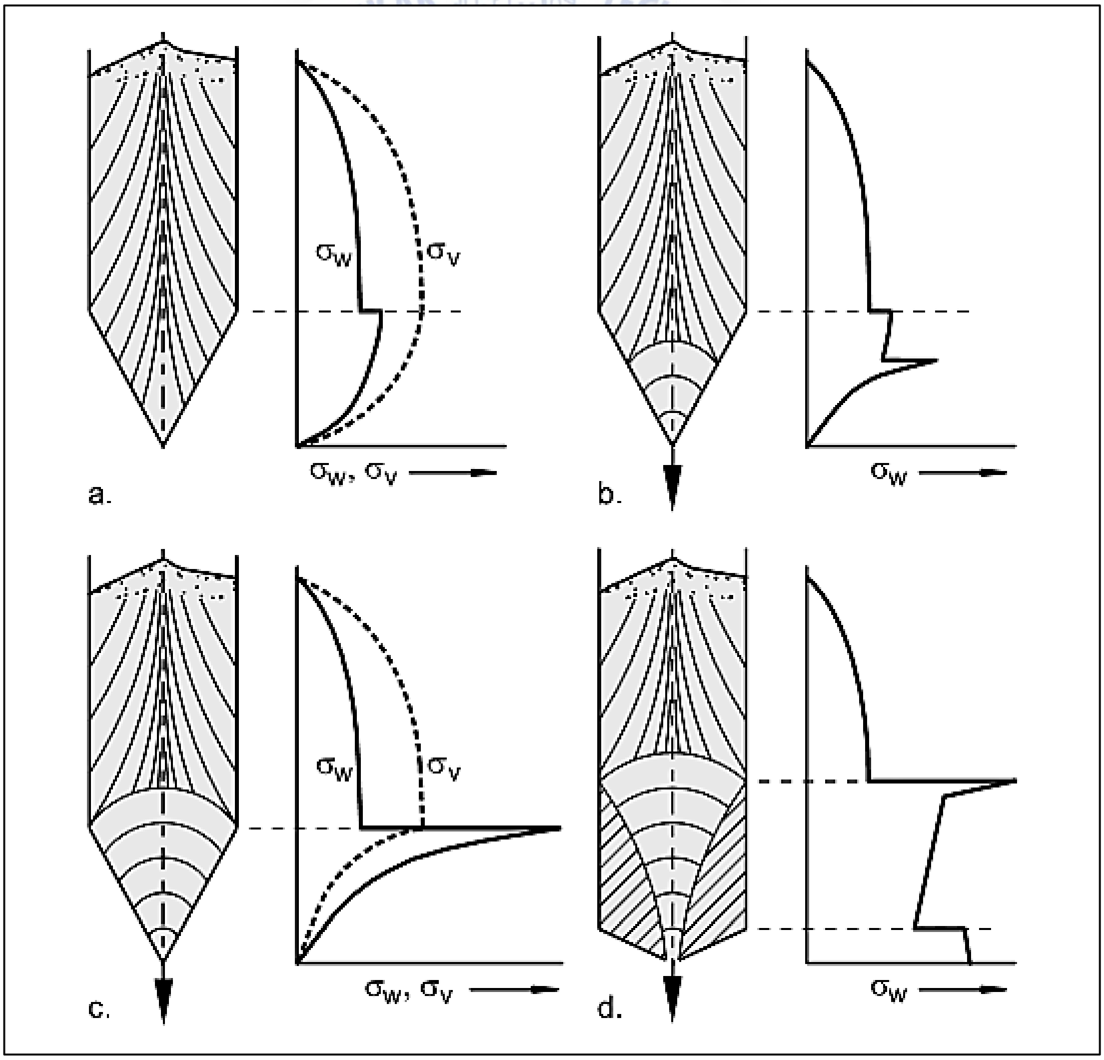


Figure 3-7 Qualitative Distributions of Wall Normal Stress and Mean Vertical Stress.

When material is discharged from a mass flow silo the first time after it has been filled, after a short transition period the entire contents of the silo moves downward. Due to the convergent flow zone in the hopper the bulk solid is compressed horizontally, while it dilates in the vertical direction due the downwards flow. As a result, the larger stresses act in the horizontal direction and the major principal stress along the hopper axis is oriented horizontally. This stress field is called “arched” or “passive” stress field. Other designations are “passive state of stress”, “emptying state of stress” or just “emptying conditions”. Fig. 3-7 (b) shows the situation a very short time after the onset of discharge, where the passive stress field has developed only in the lower part of the hopper. A bit later compared to the situation in Fig 3-7 (b), the passive stress field is fully developed (Fig.3-7-c). Here the stresses in the hopper decrease remarkably towards the apex. In the lower part of the hopper the so-called “radial stress field” develops where the local stress is nearly proportional to the distance from the hopper apex. In the emptying state the stresses close to the outlet are independent of the stresses in the upper part of the hopper and, therefore, also independent of the silo’s dimensions or level of filling.

In funnel flow, stagnant zones are formed which remain at rest while the material in the flow zone is flowing downwards (Fig. 3-7-d). If the boundary between a stagnant zone and the flow zone meets the silo wall within the vertical section, a stress peak occurs due to the “switch” from active to passive stress field caused by the convergent flow zone beneath the top of the stagnant zone. For the sake of completeness, it has to be mentioned that the large wall normal stress along the hopper walls of the funnel flow silo in (Fig. 3-7-d) results from the shallow slope of the hopper walls. Compared to mass flow, this is more difficult in funnel flow, because the stress peak acts in the sensitive vertical section where its position cannot be accurately predicted [9.9]. In addition, the stress peak can be asymmetric with respect to the perimeter, and it can change its position with time. The boundary between stagnant and flow zones does not meet the silo wall, or it meets the silo wall only near to the surface where the stresses are small. Thus, no (or no significant) stress peak develops at the silo wall.

3.4.4 Calculation of Stresses

From the considerations above it can be seen that four different cases have to be taken into account when calculating stresses in silos:

- Stresses in the vertical part of silo (active state of stress, filling state)

- Stresses in the vertical part of silo (passive state of stress, emptying state)

- Stresses in the hopper (active state of stress, filling state)

- Stresses in the hopper (passive state of stress, emptying state)

The above-mentioned stresses are analysed by using the Janssen's Equation given below:

$$P_h = \frac{wR}{\mu}(1 - \exp\left(\frac{-\mu K h}{R}\right))$$

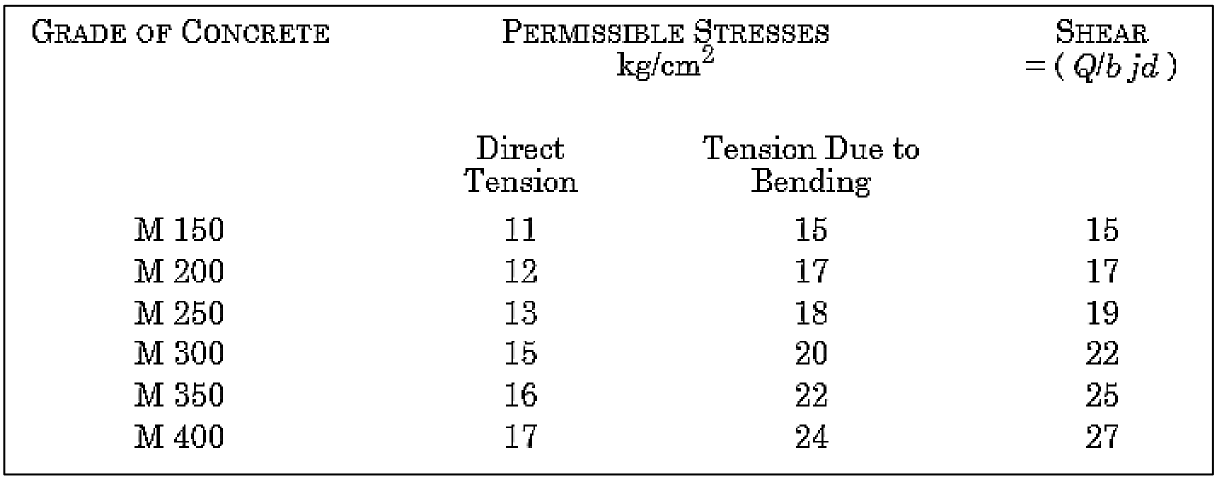
3.5 Design Specifications

3.5.1 Indian Standards on Design of Bins IS: 4995 Part 2 (1974)

3.5.1.1 Stress in Concrete for Resistance to Cracking:

The Permissible Stress in Tension (Direct and Due to Bending) and shear shall confirm to Table given below (taken by IS 3370 (Part 2)-1965). These values can be converted into N/mm^2 by using approximate relation: 10kg/cm^2≈ 1N/mm^2. The permissible tensile stresses due to bending apply to the face of the member in contact with the liquid. In members, less than 225 mm thick and in contact with the liquid on one side, these permissible stresses in bending apply also to the face remote from the liquid.

Table 3-1 Stress in Concrete



GRADE OF CONCRETE	PERMISSIBLE STRESSES kg/cm^2		SHEAR $= (Q/b\,jd)$
	Direct Tension	Tension Due to Bending	
M 150	11	15	15
M 200	12	17	17
M 250	13	18	19
M 300	15	20	22
M 350	16	22	25
M 400	17	24	27

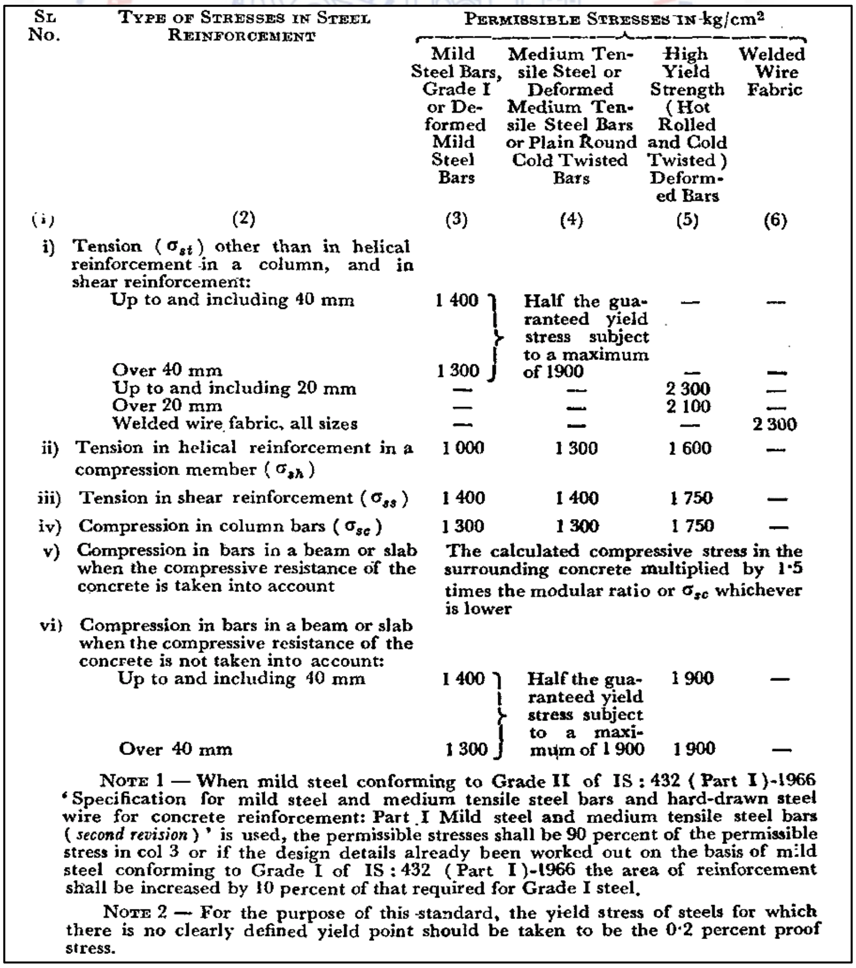
3.5.1.2 Stress in Concrete for Resistance to Buckling

The maximum compressive stress on the net wall section deducting all openings, recesses, etc., shall not exceed 0.25 f_c, where f_c is the compressive strength of concrete at the age of 28 days**.**

3.5.1.3 Stress in Steel

When steel and concrete are assumed to act together for checking the tensile stress in concrete for avoidance of cracks, the tensile stress in the steel will be limited by the requirement that the permissible tensile stress in the concrete is not exceeded; so the tensile stress in steel shall be equal to the product of modular ratio of steel and concrete, and the corresponding allowable tensile stress in concrete. For strength calculation, the stress in plain mild steel reinforcement and HYSD bars, the values are given in below table (taken by IS :3370 (Part 2)-1965). These value can be converted into N/mm^2 by using approximate relation : 10kg/cm^2≈ 1N/mm^2.

Table 3-2 Stress in Steel



SL No.	TYPE OF STRESSES IN STEEL REINFORCEMENT	PERMISSIBLE STRESSES IN kg/cm^2			
		Mild Steel Bars, Grade I or Deformed Mild Steel Bars	Medium Tensile Steel or Deformed Medium Tensile Steel Bars or Plain Round Cold Twisted Bars	High Yield Strength (Hot Rolled and Cold Twisted) Deformed Bars	Welded Wire Fabric
(1)	(2)	(3)	(4)	(5)	(6)
i)	Tension (σ_{st}) other than in helical reinforcement in a column, and in shear reinforcement:				
	Up to and including 40 mm	1 400	Half the guaranteed yield stress subject to a maximum of 1900	—	—
	Over 40 mm	1 300		—	—
	Up to and including 20 mm	—	—	2 300	—
	Over 20 mm	—	—	2 100	—
	Welded wire fabric, all sizes	—	—	—	2 300
ii)	Tension in helical reinforcement in a compression member (σ_{sh})	1 000	1 300	1 600	—
iii)	Tension in shear reinforcement (σ_{ss})	1 400	1 400	1 750	—
iv)	Compression in column bars (σ_{sc})	1 300	1 300	1 750	—
v)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1·5 times the modular ratio or σ_{sc} whichever is lower			
vi)	Compression in bars in a beam or slab when the compressive resistance of the concrete is not taken into account:				
	Up to and including 40 mm	1 400	Half the guaranteed yield stress subject to a maximum of 1 900	1 900	—
	Over 40 mm	1 300		1 900	—

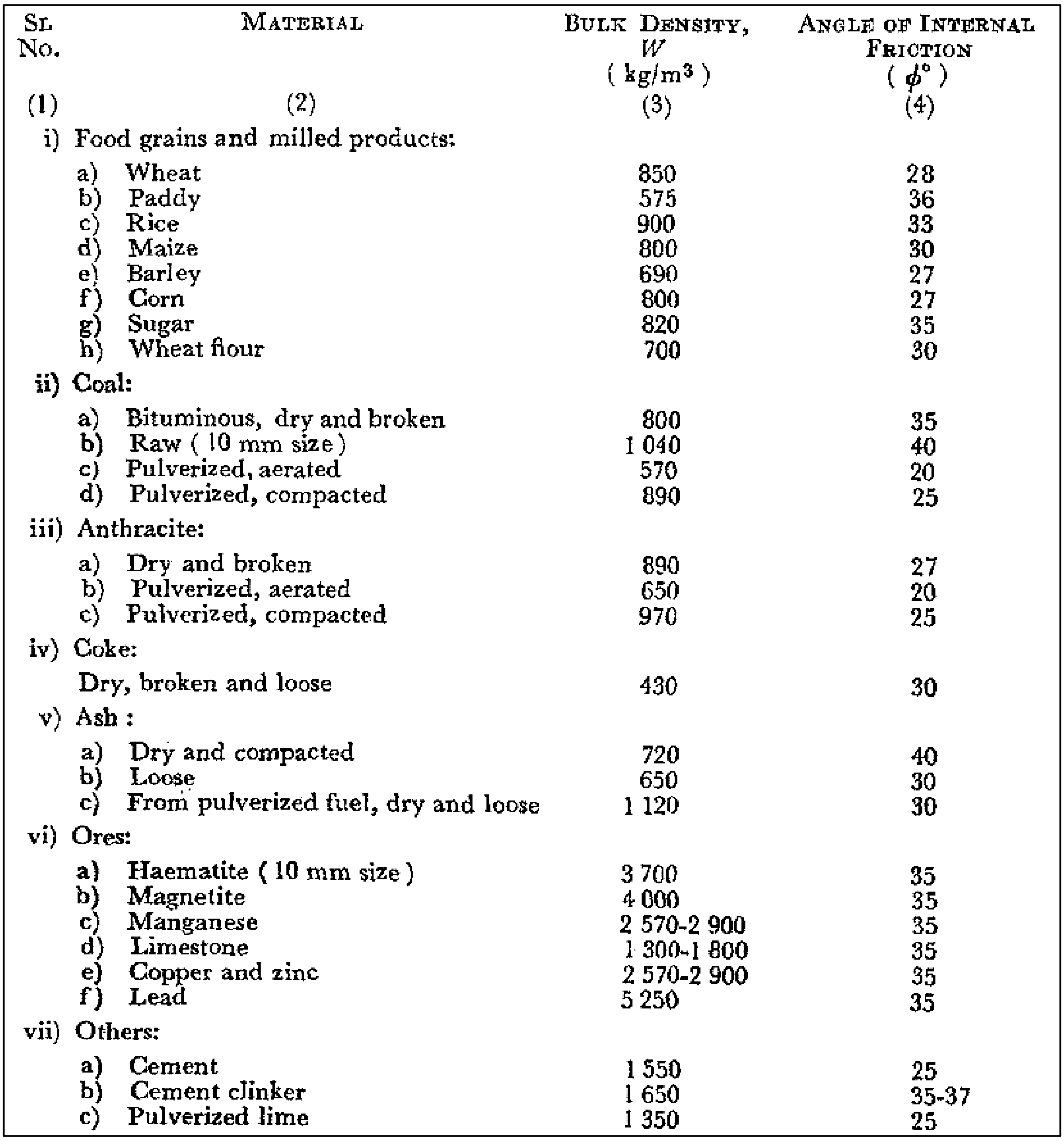
NOTE 1 — When mild steel conforming to Grade II of IS : 432 (Part I)-1966 'Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part I Mild steel and medium tensile steel bars (*second revision*)' is used, the permissible stresses shall be 90 percent of the permissible stress in col 3 or if the design details already been worked out on the basis of mild steel conforming to Grade I of IS : 432 (Part I)-1966 the area of reinforcement shall be increased by 10 percent of that required for Grade I steel.

NOTE 2 — For the purpose of this standard, the yield stress of steels for which there is no clearly defined yield point should be taken to be the 0·2 percent proof stress.

3.5.1.4 Unit Weight and Angle of Internal Friction

Below Table gives the values of bulk density and angle of internal friction for some of the commonly stored materials.

Table 3-3 Unit Weight and Angle of Friction

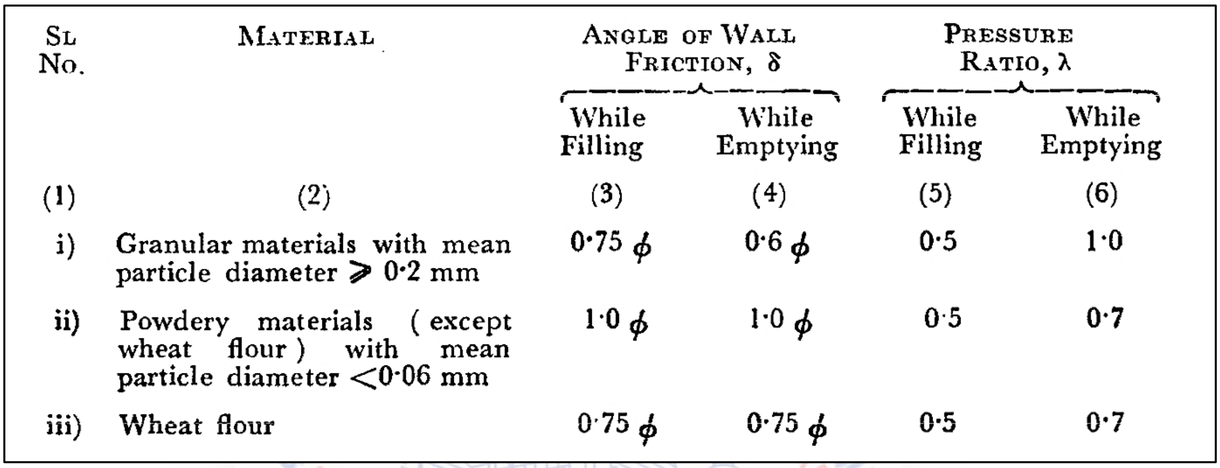


SL No.	MATERIAL	BULK DENSITY, W (kg/m^3)	ANGLE OF INTERNAL FRICTION ($\phi°$)
(1)	(2)	(3)	(4)
i)	Food grains and milled products:		
	a) Wheat	850	28
	b) Paddy	575	36
	c) Rice	900	33
	d) Maize	800	30
	e) Barley	690	27
	f) Corn	800	27
	g) Sugar	820	35
	h) Wheat flour	700	30
ii)	Coal:		
	a) Bituminous, dry and broken	800	35
	b) Raw (10 mm size)	1 040	40
	c) Pulverized, aerated	570	20
	d) Pulverized, compacted	890	25
iii)	Anthracite:		
	a) Dry and broken	890	27
	b) Pulverized, aerated	650	20
	c) Pulverized, compacted	970	25
iv)	Coke:		
	Dry, broken and loose	430	30
v)	Ash :		
	a) Dry and compacted	720	40
	b) Loose	650	30
	c) From pulverized fuel, dry and loose	1 120	30
vi)	Ores:		
	a) Haematite (10 mm size)	3 700	35
	b) Magnetite	4 000	35
	c) Manganese	2 570-2 900	35
	d) Limestone	1 300-1 800	35
	e) Copper and zinc	2 570-2 900	35
	f) Lead	5 250	35
vii)	Others:		
	a) Cement	1 550	25
	b) Cement clinker	1 650	35-37
	c) Pulverized lime	1 350	25

3.5.1.5 Wall Friction

In the absence of reliable experimental data, the angle of wall friction for granular and powdery materials: irrespective of the roughness of bin wall, may be taken as given in Table 3-11.

Table 3-4 Wall Friction



SL No.	MATERIAL	ANGLE OF WALL FRICTION, δ		PRESSURE RATIO, λ	
		While Filling	While Emptying	While Filling	While Emptying
(1)	(2)	(3)	(4)	(5)	(6)
i)	Granular materials with mean particle diameter $\geqslant$ 0·2 mm	0·75 ϕ	0·6 ϕ	0·5	1·0
ii)	Powdery materials (except wheat flour) with mean particle diameter $<$0·06 mm	1·0 ϕ	1·0 ϕ	0·5	0·7
iii)	Wheat flour	0·75 ϕ	0·75 ϕ	0·5	0·7

3.5.1.6 Wall Thickness

The wall thickness for curved walls shall be not less than the larger of the following with a minimum thickness of 10 cm.

$$t = 10 + 2.5\frac{(D-3)}{3}$$

$$t = 10 + 2.5\frac{(H-6)}{12}$$

‘t’ is in cm and ‘ D’ and ‘H’ are in m.

3.5.1.7 Circumferential Reinforcement

The minimum circumferential reinforcement shall be 0.25 percent of cross-sectional area of the bin wall when deformed bars are used. When mild steel bars are used this shall be 0.3 percent of the cross-sectional area of the bin wall. Splices in bars shall be well staggered. The bars shall be at least 8 mm in diameter. Spacing of circumfcrcntial reinforcement shall not exceed 200 mm and bar diameter shall not be less than 8 mm when deformed bars are used and 10 mm when mild steel bars are used.

3.5.1.8 Vertical Reinforcement

Vertical Reinforcement should be atleast 0.3 percent of cross-sectional area of bin walls .Half the numbers of bars on inside and other Half on the outside should be provided to take care of temperature and shrinkage stress.

3.5.1.9 Cover

A minimum clear concrete cover of 30 mm shall be provided for the reinforcement.

3.6 Selection of hopper dimensions

If a material is free flowing and is always going to remain so (no danger of increased moisture, time consolidation or caking effects) then from a purely flow perspective, core flow is adequate and there is little need to use a rational hopper design procedure such as Jenike. If your material can segregate and this bothers you, then you may need to use mass flow. If you do not know the material really well, or you are moving into new processing conditions, then really you should undertake some characterization work – at least Flow Function, Wall Friction and Bulk Density – and use a rational hopper design procedure to determine what geometry is required for reliable flow.

- **Determination of hopper outlet size and angle from the following chart:**

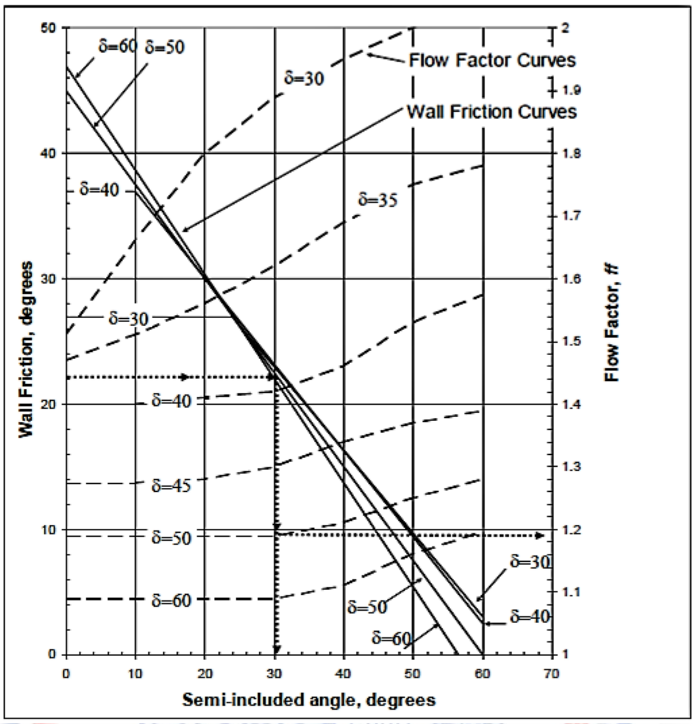


Figure 3-8 Design chart for symmetrical slot outlet hoppers

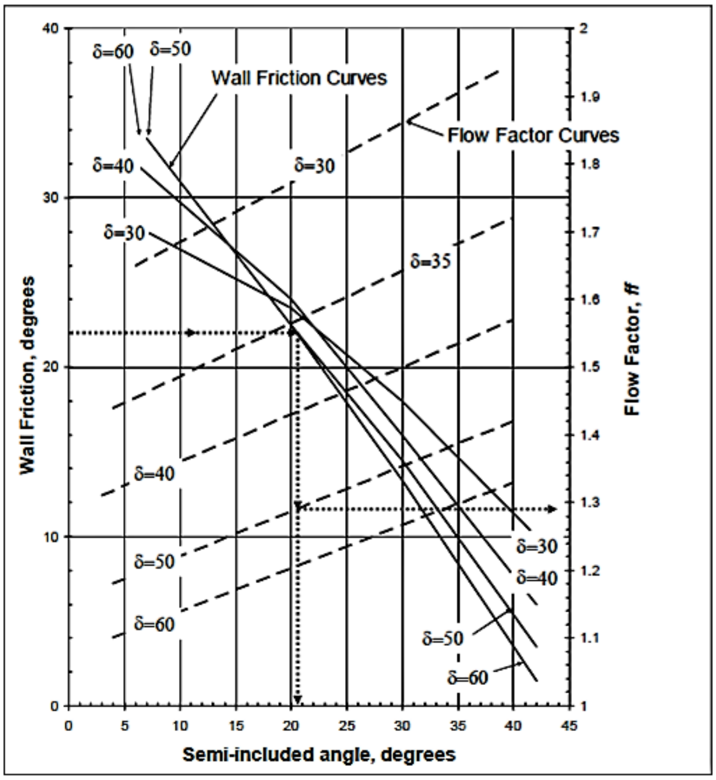


Figure 3-9 Design chart for conical outlet hoppers

The intersection of the MFF curve in Figure 7 with the line through the origin having a slope of 1/ff is the Critical Applied Stress (CAS) (Figure 8). Recall that the condition of flow (no arching) occurs for points on or above the MFF curve. Therefore the hopper should operate where the 1/ff curve is above the MFF curve, ie, above or to the right of the CAS.

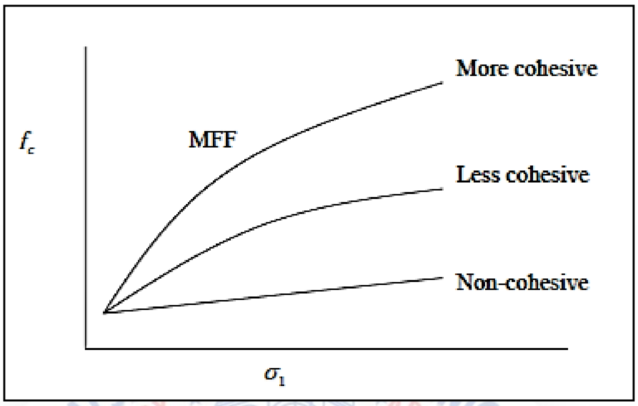


Figure 3-10 The material flow function

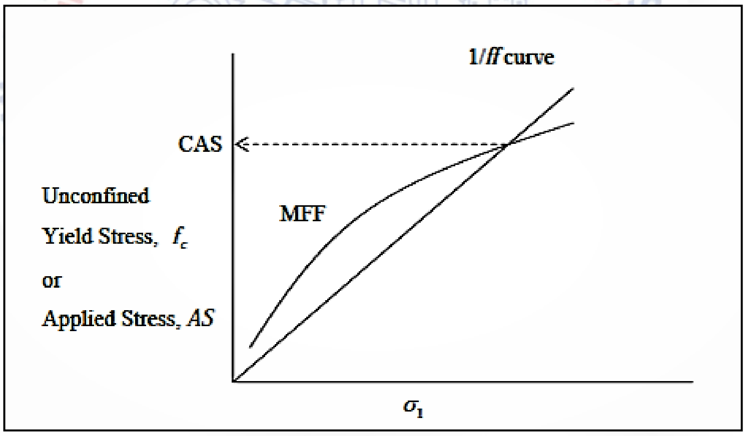


Figure 3-11 Intersection of the 1/ff and MFF curves

For conical hoppers, Figure 3-12, the opening diameter, d, is given by

$$d = H(\theta)\frac{CAS}{\rho^\circ g/gc}$$

$$H(\theta) = 2 + \frac{\theta}{60}$$

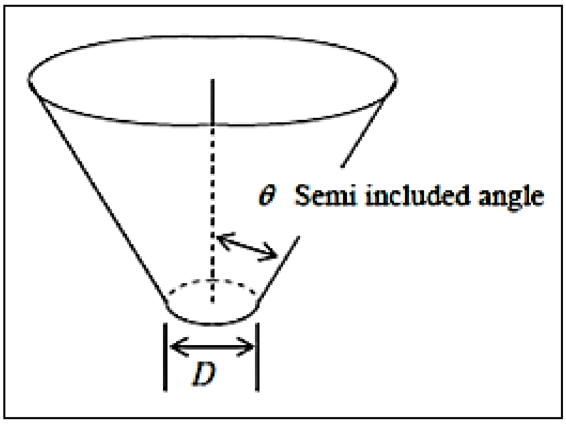


Figure 3-12 Conical Hopper

3.7 Design Procedure

- Calculation of the volume of cylindrical portion using the weight and density of material to be stored.
- Assuming suitable height, calculate radius of cylindrical portion.
- Calculate thickness of wall using formulae recommended in IS:4995(Part-2)-1974,

$$t = 10 + 2.5\frac{(D-3)}{3}$$

$$t = 10 + 2.5\frac{(H-6)}{12}$$

(The wall thickness for curved walls shall not be less than the larger of the following with a minimum thickness of 10cm)

Where,

t is in ‘cm’ and D and H are in ‘m’.

- Calculation of pressure at different height intervals of the cylindrical portion by using Janssen’s equation during **filling state**, taking coefficient of lateral pressure as 0.5.
- Now calculate hoop tension for filling condition,

$$T = \frac{P_h * b}{2}$$

- Repeat the same procedure for **emptying state** by taking coefficient of lateral pressure as one.
- Calculation of area of circumferential reinforcement for maximum hoop tension.

$$A_{sh} = \frac{T}{\sigma_{st}}$$

- Calculation of spacing of circumferential bars of suitable diameter (shall not exceed 200mm).
- Calculation of area of steel of vertical bars (nominal) i.e. 0.3% of cross-sectional area of cylindrical wall and calculate spacing accordingly.
- Calculation of total compressive stress on the wall portion due to,
  i. Vertical load (P_w) of the grains
  ii. Self load
  iii. Load of the top cover
  iv. Wind load (from IS 875(Part-3))
- Total compressive stress should be less than σ_{ct}
- Calculation of hopper dimensions as per (section 3.6).
- Calculation of weight of grain and concrete in the conical portion.

$$Weight\ of\ grain\ in\ conical\ portion = \frac{w * h}{3}[A_1 + A_2 + \sqrt{A_1 * A_2}]$$

- Calculation of total vertical load per 1m perimeter (W).
- Calculation of meridional tension (T_m) for emptying and filling conditions in hopper.

$$T_m = W * coseca$$

W will change according to emptying and filling state.

- Check for maximum meridional tension and calculate vertical steel and spacing accordingly (alternate bars may be stopped halfway).
- Calculate normal stress (p_n) and hoop tension (T) at mid-height of hopper and junction of hopper and cylindrical portion for emptying and filling state.

$$p_{n=}p_v cos^2\alpha + p_h sin^2\alpha + w_s cos\alpha$$

$$T = p_n * r_n$$

- Check for maximum hoop tension and provide circumferential bars and spacing accordingly.

Chapter 4

Results and Discussions

4.1 General

The following table shows the design of silos by computing various H/D ratios, which provide dimensions, steel and cost information for the required structure. All the design are based on the recommendation of IS 4995-1974(Part 1&2) “Criteria for Design of Reinforced Concrete Bins for the Storage of Granular and Powdery Materials” and IS: 456-2000 “Plain and Reinforced Concrete-code of practice”. Various dimensions of silos are chosen as per volume requirement and are designed with various H/D ratio. Steel quantities are found out from “Bar Bending Schedule” and Concrete quantity is found out separately. The total cost is then calculated for materials to obtain economical dimension.

4.2 Dimensions and Reinforcement

4.2.1 Dimensions of Cylindrical Portion

Table 4-1 Dimensions of Cylindrical Portion

Height of cylindrical portion (H) in 'm'	Radius of cylindrical portion (r) in 'm'	Diameter of a cylindrical portion (D) in 'm'	H/D Ratio	Hydraulic mean depth'r' (m)	T_1 'cm'	T_2 'cm'	Thickness 'm'
20.00	1.69	3.38	5.91	0.85	10.32	12.92	0.15
19.00	1.74	3.47	5.48	0.87	10.39	12.71	0.15
18.00	1.78	3.57	5.05	0.89	10.47	12.50	0.15
17.00	1.83	3.67	4.63	0.92	10.56	12.29	0.15
16.00	1.89	3.78	4.23	0.95	10.65	12.08	0.15
15.00	1.95	3.91	3.84	0.98	10.75	11.88	0.12
14.00	2.02	4.04	3.46	1.01	10.87	11.67	0.12
13.00	2.10	4.20	3.10	1.05	11.00	11.46	0.12
12.00	2.18	4.37	2.75	1.09	11.14	11.25	0.12
11.00	2.28	4.56	2.41	1.14	11.30	11.04	0.12
10.00	2.39	4.78	2.09	1.20	11.49	10.83	0.12
9.00	2.52	5.04	1.79	1.26	11.70	10.63	0.12
8.00	2.67	5.35	1.50	1.34	11.96	10.42	0.12

4.2.2 Calculation of Pressure

Table 4-2 Calculation of Pressure

Height of cylindrical portion (H) in 'm'	Horizontal Pressure At Junction (KN/m^2)		Vertical Pressure (KN/m^2)	
	Filling	**Emptying**	**Filling**	**Emptying**
20.00	19.33	19.66	38.66	19.66
19.00	19.71	20.16	39.42	20.16
18.00	20.09	20.71	40.17	20.71
17.00	20.45	21.29	40.90	21.29
16.00	20.79	21.92	41.58	21.92
15.00	21.09	22.59	42.18	22.59
14.00	21.33	23.30	42.67	23.30
13.00	21.50	24.05	43.00	24.05
12.00	21.55	24.81	43.11	24.81
11.00	21.47	25.56	42.94	25.56
10.00	21.21	26.24	42.42	26.24
9.00	20.73	26.80	41.46	26.80
8.00	19.98	27.12	39.97	27.12

4.2.3 Calculation of Circumferential Steel in Cylindrical Portion

Table 4-3 Circumferential Steel

Height of cylindrical portion	Height intervals	D (m)	r (m)	p_h (KN/m^2)	T (KN/m)	A_{sh} (mm^2)	Spacing (mm)	Spacing provided (mm)
20m	2.00	3.38	0.85	10.97	18.54	161.19	487.25	200.00
	4.00			15.85	26.79	232.94	337.17	200.00
	6.00			18.02	30.46	264.88	296.52	200.00
	8.00			18.99	32.10	279.09	281.41	200.00
	10.00			19.42	32.82	285.42	275.17	200.00
	12.00			19.61	33.15	288.24	272.49	200.00
	14.00			19.70	33.29	289.49	271.30	200.00
	16.00			19.74	33.36	290.05	270.78	200.00
	18.00			19.75	33.38	290.30	270.55	200.00
	20.00			19.76	33.40	290.41	270.45	200.00
19m	2.00	3.47	0.87	11.06	19.18	166.82	470.80	200.00
	4.00			16.07	27.88	242.48	323.91	200.00
	6.00			18.35	31.83	276.78	283.76	200.00
	8.00			19.38	33.62	292.34	268.66	200.00
	10.00			19.84	34.43	299.39	262.33	200.00
	12.00			20.06	34.80	302.59	259.56	200.00
	14.00			20.15	34.97	304.04	258.32	200.00
	16.00			20.20	35.04	304.70	257.76	200.00
	18.00			20.22	35.08	305.00	257.51	200.00
	19.00			20.22	35.08	305.08	257.44	200.00

18m	2.00	3.57	0.89	11.14	19.89	172.97	454.08	200.00
	4.00			16.29	29.07	252.81	310.67	200.00
	6.00			18.66	33.31	289.66	271.14	200.00
	8.00			19.76	35.27	306.68	256.10	200.00
	10.00			20.26	36.17	314.53	249.71	200.00
	12.00			20.50	36.59	318.16	246.86	200.00
	14.00			20.61	36.78	319.83	245.57	200.00
	16.00			20.66	36.87	320.60	244.98	200.00
	18.00			20.68	36.91	320.96	244.70	200.00
17m	2.00	3.67	0.92	11.27	20.67	179.78	436.87	200.00
	4.00			16.60	30.46	264.89	296.50	200.00
	6.00			19.13	35.10	305.18	257.36	200.00
	8.00			20.32	37.29	324.25	242.22	200.00
	10.00			20.89	38.33	333.28	235.66	200.00
	12.00			21.15	38.82	337.55	232.67	200.00
	14.00			21.28	39.05	339.58	231.29	200.00
	16.00			21.34	39.16	340.53	230.64	200.00
	17.00			21.36	39.19	340.80	230.46	200.00
16m	2.00	3.78	0.95	11.38	21.52	187.10	419.78	200.00
	4.00			16.90	31.95	277.79	282.73	200.00
	6.00			19.58	37.00	321.75	244.11	200.00
	8.00			20.87	39.45	343.05	228.94	200.00
	10.00			21.50	40.64	353.38	222.25	200.00
	12.00			21.81	41.21	358.39	219.15	200.00
	14.00			21.95	41.49	360.81	217.68	200.00
	16.00			22.03	41.63	361.99	216.97	200.00
15m	2.00	3.91	0.98	11.50	22.48	195.44	401.87	200.00
	4.00			17.19	33.61	292.29	268.71	200.00
	6.00			20.02	39.13	340.29	230.81	200.00
	8.00			21.42	41.87	364.07	215.73	200.00
	10.00			22.11	43.22	375.86	208.96	200.00

	12.00			22.45	43.90	381.70	205.76	200.00
	14.00			22.62	44.23	384.60	204.21	200.00
	15.00			22.67	44.33	385.44	203.77	200.00
14m	2.00	4.04	1.01	11.60	23.44	203.81	385.36	200.00
	4.00			17.47	35.30	306.94	255.88	200.00
	6.00			20.45	41.30	359.12	218.70	200.00
	8.00			21.95	44.34	385.53	203.72	200.00
	10.00			22.71	45.87	398.89	196.90	190.00
	12.00			23.09	46.65	405.65	193.61	190.00
	14.00			23.29	47.04	409.07	191.99	190.00
13m	2.00	4.20	1.05	11.74	24.65	214.34	366.43	200.00
	4.00			17.83	37.45	325.65	241.18	200.00
	6.00			21.00	44.10	383.45	204.82	200.00
	8.00			22.64	47.55	413.47	189.95	180.00
	10.00			23.50	49.34	429.06	183.05	180.00
	12.00			23.94	50.27	437.16	179.66	170.00
	13.00			24.07	50.55	439.60	178.66	170.00
12m	2.00	4.37	1.09	11.86	25.92	225.42	348.41	200.00
	4.00			18.18	39.71	345.34	227.43	200.00
	6.00			21.53	47.05	409.13	191.97	190.00
	8.00			23.32	50.95	443.06	177.27	170.00
	10.00			24.27	53.03	461.11	170.33	170.00
	12.00			24.77	54.13	470.71	166.85	160.00

11m	2.00	4.56	1.14	12.01	27.39	238.16	329.77	200.00
	4.00			18.58	42.37	368.41	213.18	200.00
	6.00			22.18	50.56	439.65	178.64	170.00
	8.00			24.14	55.04	478.60	164.10	160.00
	10.00			25.21	57.49	499.91	157.11	150.00
	11.00			25.55	58.26	506.61	155.03	150.00
10m	2.00	4.78	1.20	12.18	29.10	253.08	310.34	200.00
	4.00			19.04	45.51	395.72	198.47	190.00
	6.00			22.91	54.75	476.13	164.96	160.00
	8.00			25.09	59.97	521.44	150.62	150.00
	10.00			26.32	62.90	546.99	143.59	140.00
9m	2.00	5.04	1.26	12.33	31.07	270.17	290.71	200.00
	4.00			19.47	49.07	426.66	184.08	180.00
	6.00			23.61	59.49	517.31	151.82	150.00
	8.00			26.00	65.53	569.82	137.83	130.00
	9.00			26.79	67.52	587.09	133.78	130.00
8m	2.00	5.35	1.34	12.51	33.47	291.08	269.82	200.00
	4.00			20.00	53.51	465.28	168.80	160.00
	6.00			24.48	65.49	569.52	137.91	130.00
	8.00			27.17	72.67	631.90	124.29	120.00

4.2.4 Vertical Steel in Cylindrical Portion

Table 4-4 Vertical Steel in Cylindrical Portion

Height of cylindrical portion (H) in 'm'	**Vertical Reinforcement (mm^2)**	**Spacing (mm)**	**Spacing Provided (mm)**
20.00	450.00	174.53	170.00
19.00	450.00	174.53	170.00
18.00	450.00	174.53	170.00
17.00	450.00	174.53	170.00
16.00	450.00	174.53	170.00
15.00	360.00	218.17	210.00
14.00	360.00	218.17	210.00
13.00	360.00	218.17	210.00
12.00	360.00	218.17	210.00
11.00	360.00	218.17	210.00
10.00	360.00	218.17	210.00
9.00	360.00	218.17	210.00
8.00	360.00	218.17	210.00

4.2.5 Hopper Dimensions

Table 4-5 Hopper Dimensions

Semi-included angle (θ)	Height of hopper section (H') 'm'	Outlet Dia. of hopper (D') 'm'	Dia at hopper mid height d' (m)	Hydraulic mean depth(r') (m)	Curvature radius(r_n) (m)	Wt. of hopper section/m (w_s) (KN/m^2)	A_1 (m^2)	A_2 (m^2)
25.00	2.88	0.70	2.04	0.51	1.13	3.75	8.98	0.38
25.00	2.97	0.70	2.09	0.52	1.15	3.75	9.46	0.38
25.00	3.07	0.70	2.13	0.53	1.18	3.75	9.98	0.38
25.00	3.18	0.70	2.18	0.55	1.21	3.75	10.57	0.38
25.00	3.30	0.70	2.24	0.56	1.24	3.75	11.23	0.38
25.00	3.44	0.70	2.30	0.58	1.27	3.00	11.98	0.38
25.00	3.58	0.70	2.37	0.59	1.31	3.00	12.83	0.38
25.00	3.75	0.70	2.45	0.61	1.35	3.00	13.82	0.38
25.00	3.93	0.70	2.53	0.63	1.40	3.00	14.97	0.38
25.00	4.14	0.70	2.63	0.66	1.45	3.00	16.34	0.38
25.00	4.38	0.70	2.74	0.69	1.51	3.00	17.97	0.38
25.00	4.66	0.70	2.87	0.72	1.58	3.00	19.97	0.38
25.00	4.98	0.70	3.02	0.76	1.67	3.00	22.46	0.38

4.2.6 Weights Acting on Hopper

Table 4-6 Weights Acting on Hopper

Wt. of hopper section/m (w_s) (KN/m^2)	A_1 (m^2)	A_2 (m^2)	Wt. of grain in conical portion 'KN'	Wt. of concrete in conical portion 'KN'
3.75	8.98	0.38	86.12	69.06
3.75	9.46	0.38	93.07	72.60
3.75	9.98	0.38	100.99	76.52
3.75	10.57	0.38	110.10	80.87
3.75	11.23	0.38	120.66	85.76
3.00	11.98	0.38	133.00	71.94
3.00	12.83	0.38	147.59	76.90
3.00	13.82	0.38	165.03	82.61
3.00	14.97	0.38	186.18	89.23
3.00	16.34	0.38	212.24	97.01
3.00	17.97	0.38	244.98	106.30
3.00	19.97	0.38	287.06	117.58
3.00	22.46	0.38	342.68	131.60

4.2.7 Pressure on Conical Hopper (Filling State)

Table 4-7 Pressure on Conical Hopper (Filling State)

Vertical force due to flow pressure KN	**W KN/m**	**T_m KN/m**	**p_h at mid-height KN/m^2**	**p_v at mid-height KN/m^2**	**p_n at mid-height KN/m^2**	**Hoop Tension at mid-height KN/m**	**p_n at junction KN/m^2**	**Hoop Tension at junction KN/m**
347.30	47.29	52.18	11.86	23.72	15.54	17.50	24.33	27.40
372.78	49.39	54.50	12.11	24.22	15.83	18.21	24.78	28.50
401.01	51.65	56.99	12.38	24.75	16.15	19.00	25.22	29.68
432.29	54.08	59.67	12.66	25.33	16.49	19.87	25.65	30.91
466.94	56.68	62.54	12.97	25.94	16.85	20.83	26.05	32.20
505.29	57.89	63.87	13.30	26.59	16.92	21.49	26.09	33.14
547.64	60.80	67.08	13.65	27.29	17.33	22.67	26.38	34.50
594.30	63.88	70.49	14.01	28.03	17.76	23.98	26.57	35.88
645.51	67.13	74.07	14.40	28.79	18.21	25.45	26.64	37.22
701.47	70.54	77.84	14.79	29.58	18.68	27.10	26.54	38.51
762.24	74.10	81.76	15.19	30.38	19.15	28.96	26.23	39.67
827.74	77.80	85.85	15.59	31.17	19.61	31.06	25.66	40.65
897.69	81.66	90.10	15.97	31.93	20.06	33.46	24.79	41.35

4.2.8 Pressure on Conical Hopper (Emptying State)

Table 4-8 Pressure on Conical Hopper (Emptying State)

Vertical force due to flow pressure KN	**W KN/m**	**T_m KN/m**	**p_h at mid-height KN/m^2**	**p_v at mid-height KN/m^2**	**p_n at mid-height KN/m^2**	**Hoop Tension at mid-height KN/m**	**p_n at junction KN/m^2**	**Hoop Tension at junction KN/m**
176.62	31.23	34.45	11.87	11.87	13.44	15.13	21.22	23.89
190.70	32.69	36.07	12.12	12.12	13.69	15.75	21.72	24.99
206.72	34.31	37.85	12.40	12.40	13.97	16.43	22.27	26.20
225.06	36.10	39.83	12.70	12.70	14.27	17.19	22.85	27.54
246.18	38.10	42.04	13.03	13.03	14.60	18.04	23.48	29.02
270.63	38.76	42.77	13.39	13.39	14.64	18.60	23.83	30.28
299.09	41.23	45.49	13.78	13.78	15.04	19.67	24.54	32.11
332.39	44.01	48.56	14.23	14.23	15.48	20.90	25.29	34.15
371.48	47.16	52.03	14.72	14.72	15.97	22.32	26.05	36.40
417.46	50.72	55.97	15.28	15.28	16.53	23.98	26.79	38.88
471.56	54.76	60.42	15.90	15.90	17.15	25.94	27.48	41.56
535.07	59.33	65.46	16.62	16.62	17.87	28.30	28.04	44.41
609.21	64.49	71.16	17.43	17.43	18.68	31.16	28.36	47.31

4.2.9 Hopper Reinforcement

Table 4-9 Hopper Reinforcement

Maximum T_m KN/m	Maximum T KN/m	Vertical Reinforcement in hopper mm^2	Spacing Provided mm	Horizontal Reinforcement in hopper mm^2	Spacing Provided mm
52.18	27.40	453.73	170.00	238.26	200.00
54.50	28.50	473.89	160.00	247.83	200.00
56.99	29.68	495.58	150.00	258.09	200.00
59.67	30.91	518.87	150.00	268.78	200.00
62.54	32.20	543.83	140.00	280.00	200.00
63.87	33.14	555.39	140.00	288.17	200.00
67.08	34.50	583.33	130.00	300.00	200.00
70.49	35.88	612.92	120.00	312.00	200.00
74.07	37.22	644.13	120.00	323.65	200.00
77.84	38.88	676.84	110.00	338.09	200.00
81.76	41.56	710.98	110.00	361.39	200.00
85.85	44.41	746.49	100.00	386.17	200.00
90.10	47.31	783.51	100.00	411.39	190.00

4.3 Cost Estimation

4.3.1 Case 1

Steel estimation for 8m height of silos.

Table 4-10 Steel Estimation (8m Height)

Description	Height (m)	Actual no of bars provided	Length (m)	Total length (m)	Weight (Kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	8.00	81.00	13.65	1105.38	0.62	682.33
Horizontal bars of cylindrical portion	2.00	10.00	15.64	156.37	0.62	96.52
	4.00	13.00	15.64	203.28	0.62	125.48
	6.00	16.00	15.64	250.19	0.62	154.44
	8.00	17.00	15.64	265.82	0.62	164.09
Vertical bars at hopper (full)	4.98	85.00	5.95	505.40	0.62	311.97
Vertical bars at hopper (half)	4.98	85.00	3.20	271.79	0.62	167.77
Horizontal bars at hopper	0.19	1.00	16.55	16.55	0.62	10.22
	0.38	1.00	15.99	15.99	0.62	9.87
	0.57	1.00	15.43	15.43	0.62	9.53
	0.76	1.00	14.88	14.88	0.62	9.18
	0.95	1.00	14.32	14.32	0.62	8.84
	1.14	1.00	13.76	13.76	0.62	8.49
	1.33	1.00	13.20	13.20	0.62	8.15
	1.52	1.00	12.64	12.64	0.62	7.81
	1.71	1.00	12.09	12.09	0.62	7.46
	1.90	1.00	11.53	11.53	0.62	7.12

	2.09	1.00	10.97	10.97	0.62	6.77
	2.28	1.00	10.41	10.41	0.62	6.43
	2.47	1.00	9.86	9.86	0.62	6.08
	2.66	1.00	9.30	9.30	0.62	5.74
	2.85	1.00	8.74	8.74	0.62	5.39
	3.04	1.00	8.18	8.18	0.62	5.05
	3.23	1.00	7.62	7.62	0.62	4.71
	3.42	1.00	7.07	7.07	0.62	4.36
	3.61	1.00	6.51	6.51	0.62	4.02
	3.80	1.00	5.95	5.95	0.62	3.67
	3.99	1.00	5.39	5.39	0.62	3.33
	4.18	1.00	4.83	4.83	0.62	2.98
	4.37	1.00	4.28	4.28	0.62	2.64
	4.56	1.00	3.72	3.72	0.62	2.30

The below table gives the total cost estimation of materials for 8m silo height

Table 4-11 Total Cost (8m height)

Total weight of steel(kg)	1852.74
cost of steel(Rs)	111164.60
Volume of concrete in cylindrical portion(m^3)	8.16
Volume of concrete in hopper(m^3)	2.90
Total volume of concrete(m^3)	11.05
Cost per unit	66324.01
Total cost (Rs.)	177488.61

4.3.2 Case 2

Steel estimation for 10m height of silos.

Table 4-12 Steel Estimation (10m Height)

Description	Height (m)	Actual no of bars provided	Length (m)	Total length (m)	Weight (Kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	10.00	76.00	15.01	1140.49	0.62	704.01
Horizontal bars of cylindrical portion	2.00	10.00	15.64	156.37	0.62	96.52
	4.00	11.00	15.64	172.00	0.62	106.17
	6.00	13.00	15.64	203.28	0.62	125.48
	8.00	14.00	15.64	218.91	0.62	135.13
	10.00	15.00	15.64	234.55	0.62	144.78
Vertical bars at hopper (full)	4.40	70.00	5.31	371.40	0.62	229.26
Vertical bars at hopper (half)	4.40	70.00	2.88	201.42	0.62	124.33
Horizontal bars at hopper	0.20	1.00	14.79	14.79	0.62	9.13
	0.40	1.00	14.21	14.21	0.62	8.77
	0.60	1.00	13.62	13.62	0.62	8.41
	0.80	1.00	13.03	13.03	0.62	8.04
	1.00	1.00	12.44	12.44	0.62	7.68
	1.20	1.00	11.86	11.86	0.62	7.32
	1.40	1.00	11.27	11.27	0.62	6.96
	1.60	1.00	10.68	10.68	0.62	6.59
	1.80	1.00	10.09	10.09	0.62	6.23

	2.00	1.00	9.51	9.51	0.62	5.87
	2.20	1.00	8.92	8.92	0.62	5.51
	2.40	1.00	8.33	8.33	0.62	5.14
	2.60	1.00	7.75	7.75	0.62	4.78
	2.80	1.00	7.16	7.16	0.62	4.42
	3.00	1.00	6.57	6.57	0.62	4.06
	3.20	1.00	5.98	5.98	0.62	3.69
	3.40	1.00	5.40	5.40	0.62	3.33
	3.60	1.00	4.81	4.81	0.62	2.97
	3.80	1.00	4.22	4.22	0.62	2.61
	4.00	1.00	3.64	3.64	0.62	2.24
	4.20	1.00	3.05	3.05	0.62	1.88

The below table gives the total cost estimation of materials for 10m silo height

Table 4-13 Total Cost (10m height)

Total weight of steel	1781.32
Cost	106879.49
Volume of concrete in cylindrical portion	9.16
Volume of concrete in hopper	2.33
Total volume of concrete	11.49
Cost per unit	68948.66
Total cost (Rs.)	175828.15

4.3.3 Case 3

Steel estimation for 12m height of silos.

Table 4-14 Steel Estimation (12m Height)

Description	Height (m)	Actual no of bars provided	Length (m)	Total length (m)	Weight (kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	12.00	66.00	16.49	1088.19	0.62	671.72
Horizontal bars of cylindrical portion	2.00	10.00	15.64	156.37	0.62	96.52
	4.00	11.00	15.64	172.00	0.62	106.17
	6.00	11.00	15.64	172.00	0.62	106.17
	8.00	12.00	15.64	187.64	0.62	115.83
	10.00	12.00	15.64	187.64	0.62	115.83
	12.00	13.00	15.64	203.28	0.62	125.48
Vertical bars at hopper (full)	3.93	63.00	4.79	301.58	0.62	186.16
Vertical bars at hopper (half)	3.93	63.00	2.62	164.94	0.62	101.81
Horizontal bars at hopper	0.20	1.00	13.44	13.44	0.62	8.30
	0.40	1.00	12.85	12.85	0.62	7.93
	0.60	1.00	12.27	12.27	0.62	7.57
	0.80	1.00	11.68	11.68	0.62	7.21
	1.00	1.00	11.09	11.09	0.62	6.85
	1.20	1.00	10.51	10.51	0.62	6.48
	1.40	1.00	9.92	9.92	0.62	6.12

	1.60	1.00	9.33	9.33	0.62	5.76
	1.80	1.00	8.74	8.74	0.62	5.40
	2.00	1.00	8.16	8.16	0.62	5.03
	2.20	1.00	7.57	7.57	0.62	4.67
	2.40	1.00	6.98	6.98	0.62	4.31
	2.60	1.00	6.39	6.39	0.62	3.95
	2.80	1.00	5.81	5.81	0.62	3.59
	3.00	1.00	5.22	5.22	0.62	3.22
	3.20	1.00	4.63	4.63	0.62	2.86
	3.40	1.00	4.05	4.05	0.62	2.50
	3.60	1.00	3.46	3.46	0.62	2.14

The below table gives the total cost estimation of materials for 12m silo height

Table 4-15 Total Cost (12m height)

Total weight of steel(kg)	1719.59
Cost of steel(Rs)	103175.39
Volume of concrete in cylindrical portion(m^3)	10.02
Volume of concrete in hopper(m^3)	1.92
Total volume of concrete(m^3)	11.94
Cost per unit	71656.61
Total cost (Rs.)	174832.00

4.3.4 Case 4

Steel estimation for 14m height of silos.

Table 4-16 Steel Estimation (14m Height)

Description	Height (m)	Actual no of bar provided	Length (m)	Total length (m)	Weight (kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	14.00	62.00	18.10	1122.29	0.62	692.77
Horizontal bars of cylindrical portion	2.00	10.00	15.64	156.37	0.62	96.52
	4.00	10.00	15.64	156.37	0.62	96.52
	6.00	10.00	15.64	156.37	0.62	96.52
	8.00	10.00	15.64	156.37	0.62	96.52
	10.00	11.00	15.64	172.00	0.62	106.17
	12.00	11.00	15.64	172.00	0.62	106.17
	14.00	11.00	15.64	172.00	0.62	106.17
Vertical bars at hopper (full)	3.58	50.00	4.40	220.03	0.62	135.82
Vertical bars at hopper (half)	3.58	50.00	2.42	121.24	0.62	74.84
Horizontal bars at hopper	0.20	1.00	12.40	12.40	0.62	7.66
	0.40	1.00	11.82	11.82	0.62	7.29
	0.60	1.00	11.23	11.23	0.62	6.93
	0.80	1.00	10.64	10.64	0.62	6.57
	1.00	1.00	10.06	10.06	0.62	6.21
	1.20	1.00	9.47	9.47	0.62	5.84
	1.40	1.00	8.88	8.88	0.62	5.48

	1.60	1.00	8.29	8.29	0.62	5.12
	1.80	1.00	7.71	7.71	0.62	4.76
	2.00	1.00	7.12	7.12	0.62	4.39
	2.20	1.00	6.53	6.53	0.62	4.03
	2.40	1.00	5.95	5.95	0.62	3.67
	2.60	1.00	5.36	5.36	0.62	3.31
	2.80	1.00	4.77	4.77	0.62	2.95
	3.00	1.00	4.18	4.18	0.62	2.58
	3.20	1.00	3.60	3.60	0.62	2.22

The below table gives the total cost estimation of materials for 14m silo height

Table 4-17 Total Cost (14m height)

Total weight of steel(kg)	1687.07
Cost of steel(Rs)	101224.04
Volume of concrete in cylindrical portion(m^3)	10.82
Volume of concrete in hopper(m^3)	1.64
Total volume of concrete(m^3)	12.46
Cost per unit	74756.66
Total cost (Rs.)	175980.70

4.3.5 Case 5

Steel estimation for 16m height of silos.

Table 4-18 Steel Estimation (16m Height)

Description	Height (m)	Actual no of bar provided	Length (m)	Total length (m)	Weight (kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	16.00	71.00	19.79	1405.26	0.62	867.44
Horizontal bars of cylindrical portion	2.00	11.00	15.73	173.04	0.62	106.81
	4.00	11.00	15.73	173.04	0.62	106.81
	6.00	11.00	15.73	173.04	0.62	106.81
	8.00	11.00	15.73	173.04	0.62	106.81
	10.00	11.00	15.73	173.04	0.62	106.81
	12.00	11.00	15.73	173.04	0.62	106.81
	14.00	11.00	15.73	173.04	0.62	106.81
	16.00	11.00	15.73	173.04	0.62	106.81
Vertical bars at hopper (full)	3.30	43.00	4.09	175.94	0.62	108.60
Vertical bars at hopper (half)	3.30	43.00	2.27	97.63	0.62	60.26
Horizontal bars at hopper	0.20	1.00	11.62	11.62	0.62	7.17
	0.40	1.00	11.03	11.03	0.62	6.81
	0.60	1.00	10.44	10.44	0.62	6.45
	0.80	1.00	9.86	9.86	0.62	6.08
	1.00	1.00	9.27	9.27	0.62	5.72
	1.20	1.00	8.68	8.68	0.62	5.36

	1.40	1.00	8.09	8.09	0.62	5.00
	1.60	1.00	7.51	7.51	0.62	4.63
	1.80	1.00	6.92	6.92	0.62	4.27
	2.00	1.00	6.33	6.33	0.62	3.91
	2.20	1.00	5.75	5.75	0.62	3.55
	2.40	1.00	5.16	5.16	0.62	3.18
	2.60	1.00	4.57	4.57	0.62	2.82
	2.80	1.00	3.98	3.98	0.62	2.46
	3.00	1.00	3.40	3.40	0.62	2.10

The below table gives the total cost estimation of materials for 16m silo height

Table 4-19 Total Cost (16m height)

Total weight of steel(kg)	1960.34
Cost of steel(Rs)	117620.44
Volume of concrete in cylindrical portion(m^3)	14.53
Volume of concrete in hopper(m^3)	1.80
Total volume of concrete(m^3)	16.33
Cost per unit	97998.13
Total cost (Rs.)	215618.57

4.3.6 Case 6

Steel estimation for 18m height of silos.

Table 4-20 Steel Estimation (18m Height)

Description	Height (m)	Actual no of bar provided	Length (m)	Total length (m)	Weight (kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	18.00	67.00	21.54	1443.08	0.62	890.79
Horizontal bars of cylindrical portion	2.00	10.00	15.73	157.31	0.62	97.10
	4.00	10.00	15.73	157.31	0.62	97.10
	6.00	10.00	15.73	157.31	0.62	97.10
	8.00	10.00	15.73	157.31	0.62	97.10
	10.00	10.00	15.73	157.31	0.62	97.10
	12.00	10.00	15.73	157.31	0.62	97.10
	14.00	10.00	15.73	157.31	0.62	97.10
	16.00	10.00	15.73	157.31	0.62	97.10
	18.00	10.00	15.73	157.31	0.62	97.10
Vertical bars at hopper (full)	3.07	38.00	3.84	145.83	0.62	90.02
Vertical bars at hopper (half)	3.07	38.00	2.14	81.45	0.62	50.28
Horizontal bars at hopper	0.20	1.00	10.96	10.96	0.62	6.76
	0.40	1.00	10.37	10.37	0.62	6.40
	0.60	1.00	9.78	9.78	0.62	6.04
	0.80	1.00	9.20	9.20	0.62	5.68

	1.00	1.00	8.61	8.61	0.62	5.31
	1.20	1.00	8.02	8.02	0.62	4.95
	1.40	1.00	7.43	7.43	0.62	4.59
	1.60	1.00	6.85	6.85	0.62	4.23
	1.80	1.00	6.26	6.26	0.62	3.86
	2.00	1.00	5.67	5.67	0.62	3.50
	2.20	1.00	5.09	5.09	0.62	3.14
	2.40	1.00	4.50	4.50	0.62	2.78
	2.60	1.00	3.91	3.91	0.62	2.41

The below table gives the total cost estimation of materials for 16m silo height

Table 4-21 Total Cost (18m height)

Total weight of steel(kg)	1964.69
Cost of steel(Rs)	117881.40
Volume of concrete in cylindrical portion(m^3)	15.46
Volume of concrete in hopper(m^3)	1.60
Total volume of concrete(m^3)	17.06
Cost per unit	102345.60
Total cost (Rs.)	220226.99

4.3.7 Case 7

Steel estimation for 20m height of silos.

Table 4-22 Steel Estimation (20m Height)

Description	Height (m)	Actual no of bar provided	Length (m)	Total length (m)	Weight (kg/m)	Total weight (kg)
Vertical bars of cylindrical portion	20.00	64.00	23.33	1493.04	0.62	921.63
Horizontal bars of cylindrical portion	2.00	10.00	15.73	157.31	0.62	97.10
	4.00	10.00	15.73	157.31	0.62	97.10
	6.00	10.00	15.73	157.31	0.62	97.10
	8.00	10.00	15.73	157.31	0.62	97.10
	10.00	10.00	15.73	157.31	0.62	97.10
	12.00	10.00	15.73	157.31	0.62	97.10
	14.00	10.00	15.73	157.31	0.62	97.10
	16.00	10.00	15.73	157.31	0.62	97.10
	18.00	10.00	15.73	157.31	0.62	97.10
	20.00	10.00	15.73	157.31	0.62	97.10
Vertical bars at hopper (full)	2.88	32.00	3.63	116.10	0.62	71.66
Vertical bars at hopper (half)	2.88	32.00	2.04	65.23	0.62	40.27
Horizontal bars at hopper	0.20	1.00	10.36	10.36	0.62	6.40
	0.40	1.00	9.77	9.77	0.62	6.03
	0.60	1.00	9.19	9.19	0.62	5.67

	0.80	1.00	8.60	8.60	0.62	5.31
	1.00	1.00	8.01	8.01	0.62	4.95
	1.20	1.00	7.43	7.43	0.62	4.58
	1.40	1.00	6.84	6.84	0.62	4.22
	1.60	1.00	6.25	6.25	0.62	3.86
	1.80	1.00	5.66	5.66	0.62	3.50
	2.00	1.00	5.08	5.08	0.62	3.13
	2.20	1.00	4.49	4.49	0.62	2.77
	2.40	1.00	3.90	3.90	0.62	2.41

The below table gives the total cost estimation of materials for 16m silo height

Table 4-23 Total Cost (20m height)

Total weight of steel(kg)	2057.43
Cost of steel(Rs)	123445.99
Volume of concrete in cylindrical portion(m^3)	16.28
Volume of concrete in hopper(m^3)	1.44
Total volume of concrete(m^3)	17.72
Cost per unit	106299.05
Total cost (Rs.)	229745.05

4.4 Discussions

The below table shows the abstract sheet for the cases in the section 4.3.

Table 4-24 Abstract Sheet

Height of cylindrical portion (m)	Top dia.of cylindrical portion (m)	H/D ratio	Volume of Concrete (m^3)	Rate per Unit	Weight of Steel (kg)	Rate per Unit	Total Cost (INR)
8.00	5.35	1.50	11.05	6000.00	1852.74	60.00	177464.40
10.00	4.80	2.08	11.49	6000.00	1781.32	60.00	175819.20
12.00	4.37	2.75	11.94	6000.00	1719.59	60.00	174815.40
14.00	4.04	3.47	12.46	6000.00	1687.07	60.00	175984.20
16.00	3.78	4.23	16.33	6000.00	1960.34	60.00	215600.40
18.00	3.57	5.04	17.06	6000.00	1964.69	60.00	220241.40
20.00	3.38	5.92	17.72	6000.00	2057.43	60.00	229765.80

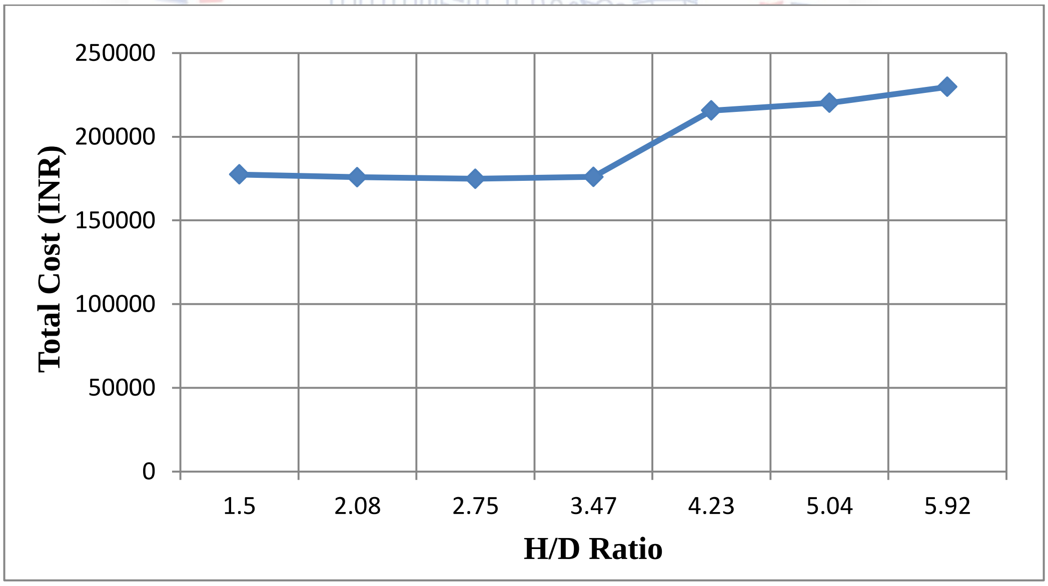


Figure 4-1 Variation of Cost with H/D Ratio

From the above Fig. 4-1, it is noted that from H/D ratio of 1.5 to 3.47, there is not much practicable difference in the construction cost of the silo. After this point there is enormous change in the cost, hence for designing an economical silo, proper H/D ratio shall be adopted.

Chapter 5

Conclusion

5.1 Conclusion

From the Cost Estimation and Abstract sheet (Refer section 4.3 and section 4.4) for various H/D Ratio it can be concluded that for coal of 160 tonnes , the H/D Ratio between 2.5-2.75 is found to be most economical (considering only material cost) .

From Jenike’s method, for analysis of hopper outlet diameter and slope for proper mass flow may give some absurd value. Hopper may prove uneconomical if not designed with respect to proper H/D Ratio, as the ratio increases the total cost of materials also increases and it will also lead to increase in the dimensons of hopper specially height to meet the angle for proper flow. It can be advisable to use Jenike’s chart to obtain mass flow should be used only if the material stored is not smooth and liable to form rathole and cake.

5.2 Scope for Future Work

1. Similar work can be carried out for steel silo.

2. Use of steel or concrete in construction of silos is a general trend, but in current market, there are new alternative materials availiable which can be used instead of concrete and steel.
3. Similary the silos can be design using Finite Element Method by means of software such as RFEM.

Chapter 6

Appendix: Typical Design of Silo for 10 m Height

6.1 General Considerations:

Weight of coal = 150 tonnes

Density of coal = 8 KN/m^3

$\mu = 0.578$

$\mu' = 0.344$

Volume of coal = $\frac{weight\ of\ coal}{density\ of\ coal} = \frac{160*1000*9.81}{8*1000} = \approx 180$ m^3.

Therefore, designing a cylindrical portion for 180 m^3.

Taking height of cylindrical portion (H) = 10 m.

Radius of cylindrical portion (R) = $\sqrt{\frac{V}{\pi H}} = \sqrt{\frac{180}{\pi * 10}} = 2.4$ m.

IS: 4995(Part 2) - 1974 recommends the following minimum thickness:

$$t = 10 + 2.5\frac{(D-3)}{3}$$

$$t = 10 + 2.5\frac{(H-6)}{12}$$

The wall thickness for curved walls shall not be less than the larger of the following with a minimum thickness of 10cm.

Vertical Reinforcement:

$$t = 10 + 2.5\frac{(D-3)}{3} = 10 + 2.5\frac{(4.8-3)}{3} = 11.5\ cm$$

$$t = 10 + 2.5\frac{(H-6)}{12} = 10 + 2.5\frac{(10-6)}{12} = 10.83cm$$

Taking the larger value from both the equation t=11.5 which is approximately equals to 12cm.

Providing vertical steel 0.3% of cross sectional area :

$$\frac{0.3}{100} * 120 * 1000 = 360\ mm^2$$

$$Spacing\ of\ 10mm\emptyset\ \text{bars} = \frac{1000 * 78.5}{360} = 218.05\text{mm} \approx 200\text{mm}$$

6.1.1 Pressure on cylindrical portion during filling:

The horizontal pressure is given by following equation,

$$p_h = \frac{w * r}{\mu'}\left[1 - e^{\frac{-\mu' K_f H}{r}}\right]$$

K_f= 0.5

r = D/4 = 4.8/4 = 1.2 m

$$p_h = \frac{8000 * 1.2}{0.344}\left[1 - e^{\frac{-0.344*0.5*H}{1.2}}\right] = 27906.97[1 - e^{-0.143H}]$$

Reinforcement required for Hoop Tension:

Using M20 grade of concrete and mild steel bars：

Height (m)	Horizontal Pressure (P_h) (N/m^2)	Hoop Tension (T) (N/m^2)	Area Of Steel (A_{sh}) (mm^2)	Reiforcement
2	6941.506715	16659.61612	144.8662271	12mm Ø @ 200mm
4	12156.40121	29175.3629	253.6988078	12mm Ø @ 200mm
6	16074.15649	38577.97557	335.4606571	12mm Ø @ 200mm
8	19017.41957	45641.80696	396.8852779	12mm Ø @ 200mm
10	21228.58309	50948.59941	443.0312992	12mm Ø @ 200mm

From the following figure it can be noted that, as the height increases, horizontal pressure also increases during filling condition.

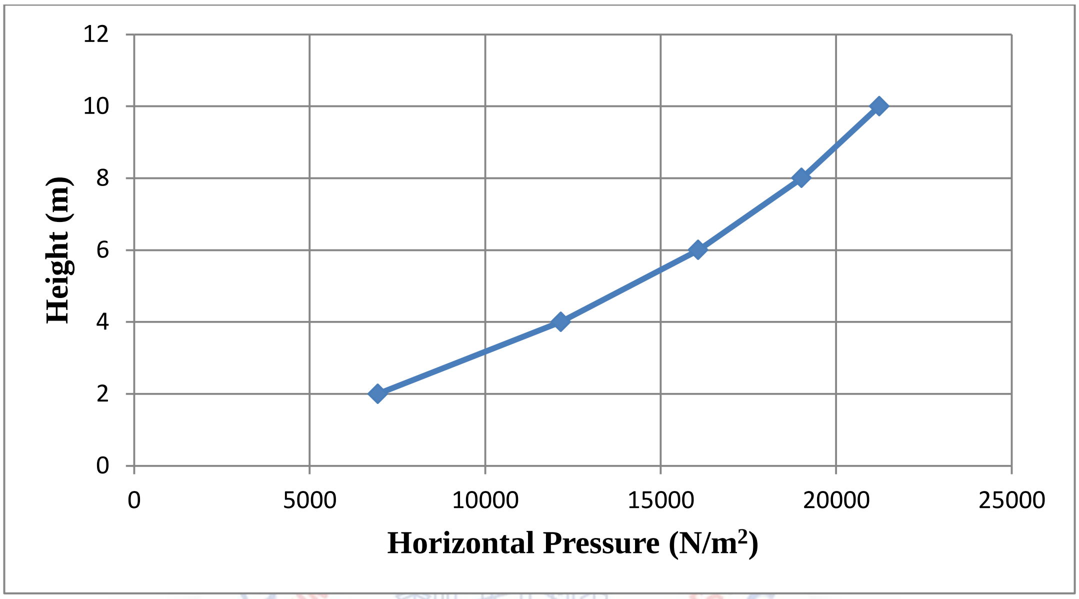


Figure 6-1 Variation Of Horizontal Pressure With Height (Filling State)

Vertical pressure at 10m height

$$P_v = \frac{P_h}{K_f} = \frac{21228.58}{0.5} = 42457.16\ N/m^2$$

6.1.2 Pressure on cylindrical portion during emptying:

$K_e = 1$

$$p_h = \frac{w * r}{\mu'}\left[1 - e^{\frac{-\mu' K_e H}{r}}\right]$$

r = D/4 = 4.8/4 = 1.2 m

$$p_h = \frac{8000 * 1.2}{0.344}\left[1 - e^{\frac{-0.344*1*H}{1.2}}\right] = 27906.97(1 - e^{-0.286H})$$

Reinforcement required for Hoop Tension:

Using M20 grade of concrete and mild steel bars :

Height (m)	Horizontal Pressure (P_h) (N/m^2)	Hoop Tension (T) (N/m)	Area Of Steel (A_{sh}) (mm^2)	Reiforcement
2	12156.40121	29175.3629	253.7	10mm Ø @ 200mm c/c
4	19017.41957	45641.80697	396.885	10mm Ø @ 190mm c/c
6	22889.74758	54935.39419	477.7	10mm Ø @ 160mm c/c
8	25075.27215	60180.65316	523.31	10mm Ø @ 150mm c/c
10	26308.77243	63141.05383	549.05	10mm Ø @ 140mm c/c

From the following figure it can be noted that, as the height increases, horizontal pressure also increases during emptying condition.

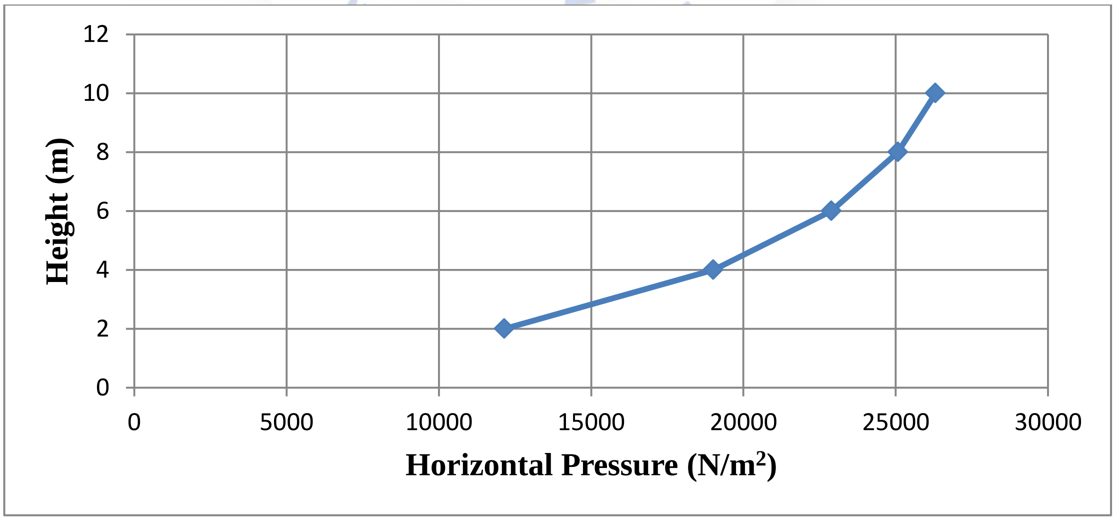


Figure 6-2 Variation Of Horizontal Pressure With Height (Emptying State)

Vertical pressure at 10m height

$$P_v = \frac{P_h}{K_e} = \frac{26308.77243}{1} = 26308.77243\ N/m^2$$

From the above calculation , It is concluded that horizontal pressure is maximum during emptying , while the vertical pressure is maximum during filling.

Provide horizontal reinforcement as follows,

First 2m , 10mm Ø @ 2000mm c/c

Next 2m , 10mm Ø @ 190mm c/c

Next 2m , 10mm Ø @ 160mm c/c

Next 2m , 10mm Ø @ 150mm c/c

Last 2m , 10mm Ø @ 140mm c/c

6.1.3 Test of wall portion as column

The wall portion is subjected to compressive stress due to the following

- Vertical load P_w of the grains , transferred to it due to friction.
- Self load
- Load of the top cover
- Wind load

Let us provide a flat roof of 12cm thickness

$$Load\ imposed\ by\ the\ roof = 0.12 * \frac{\pi * D^2}{4} * 25000 = 0.12 * \frac{\pi * 4.8^2}{4} * 25000$$

$$= 54286.72\ N$$

$$Load\ imposed\ uniformly\ over\ the\ perimeter\ of\ a\ silo\ wall = \frac{54286.72}{\pi * 4.8} = 3600 N/m$$

Vertical load due to self weight of the wall = 0.12 * 10 * 25000 = 30000 N/m

Vertical load P_w of the grains , transferred to it due to friction is given by

$$P_w = \frac{\pi * 4.8^2}{4}(8000 * 10 - 42457.16) = 679359.22\ N$$

$$Grain\ load\ over\ the\ perimeter = \frac{679359.22}{\pi * 4.8} = 45051.4\ N/m$$

Total vertical load = 3600 + 30000 + 45051.4 = 78651.4 N/m

$$f_c = \frac{78651.4}{120 * 1000} = 0.655\ N/mm^2$$

Wind pressure calculation: (from IS 875 part 3)

For Mumbai (zone 3) V_b= 44m/sec

Risk coefficient factor (k_1) = 1.07

Terrain and height factor (k_2) = 0.97

Topography factor (k_3) = 1.00

Cyclonic region factor (k_4) = 1.15

Wind directionaliy factor (K_d) = 1.0

Area averaging factor (K_a) = 0.87

Design wind speed = $V_z = V_{b*} k_{1*} k_2 * k_3 * k_4$ = 44*1.07*0.97*1.0*1.15 = 52.51m/s

Wind pressure at height z(p_z) = 0.6* $(V_z)^2$ = 0.6 * 52.51^2 = 1654.38 N/m^2

Design wind pressure (p_d) = $K_a * K_d * p_z$ = 0.87 * 1.0 * 1654.38 = 1440 N/m^2

Taking a shape factor of 0.7

Bending moment at the bottom of the cylindrical portion is

$$M = (1440 * 5.04 * 10 * 0.7) * \frac{10}{2} = 254016\ Nm$$

$$I = \frac{\pi}{64}\left[(5.04)^4 - (4.8)^4\right] = 5.615\ m^4$$

$$z = \frac{I}{y} = \frac{5.615}{2.52} = 2.228 m^3$$

$$Maximum\ bending\ stress\ due\ to\ wind\ load = \frac{M}{z} = \frac{254016}{2.228} = 114011\ N/m^2$$

$$= 0.114\ N/mm^2$$

Total compressive stress = 0.651 + 0.114 = 0.765 N/mm^2 > 0.25 * 20 = 5 N/mm^2

Hence it is safe

6.1.4 Hopper design :

μ = 0.578

Therefore , angle of internal friction = tan^{-1}(0.578) = 30^0

μ´ = 0.344

Wall friction angle = tan^{-1} (0.344) = 19^0

1/ff	
Applied stress (KPa)	**Yeild stress (KPa)**
0.0	0.0
1.0	0.5
2.0	1.1
3.0	1.6
4.0	2.2
5.0	2.7

MFF	
Applied stress (KPa)	**Yeild stress (KPa)**
0.0	0.0
1.0	1.0
2.0	1.5
3.0	1.9
4.0	2.3
5.0	2.6

By using the chart mention in figure 3.6

Hopper angle (θ) = 28^0

For a safety purpose decreasing anle by 3^0

Therefore , θ= 25^0

Flow factor (ff) = 1.82

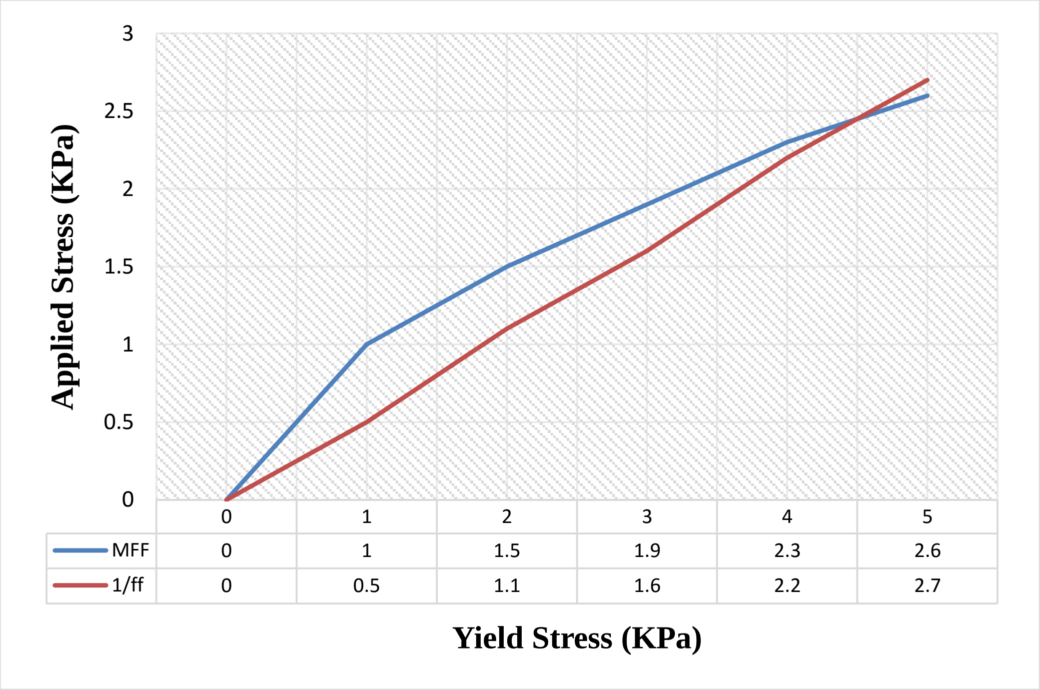


Figure 6-3 CAS Determination

Critical applied stress (CAS) = 2.4 KPa

$$H(\theta) = 2 + \frac{\theta}{60} = 2 + \frac{25}{60} = 2.41$$

$$d = H(\theta)\frac{CAS}{\rho^{\circ} g} = \ 2.41\ \frac{2.4 * 1000}{8000} = 0.7m$$

Conical hopper (filling condition):

$$P_v = 42457.16 * \frac{\pi * 4.8^2}{4} = 768286N$$

$$Grain\ load\ intensity\ on\ conical\ portion = \frac{\frac{\pi}{4}D^2Hw - \pi DP_w}{\frac{\pi}{4}D^2}$$

$$= \frac{\frac{\pi}{4} * 4.8^2 * 10 * 8000 - \pi * 4.8 * 45051.4}{\frac{\pi}{4} * 4.8^2} = 42457\frac{N}{m^2}$$

$$Weight\ of\ grain\ in\ conical\ portion = \frac{w * h}{3}[A_1 + A_2 + \sqrt{A_1 * A_2}]$$

$$A_1 = \frac{\pi * 4.8^2}{4} = 18.09m^2$$

$$A_2 = \frac{\pi * 0.7^2}{4} = 0.384m$$

$$Weight\ of\ grain\ in\ conical\ portion = \frac{8000 * 4.4}{3}[18.09 + 0.384 + \sqrt{18.09 * 0.384}]$$

$$= 247686.35N = 247.6KN$$

Assuming a thickness 0f 120mm

$$Weight\ of\ concrete\ in\ conical\ portion$$

$$= 25000 * \frac{4.4}{3}[\frac{\pi(5.04^2 - 4.8^2)}{4} + \frac{\pi(0.94^2 - 0.7^2)}{4}$$

$$+ \frac{\pi}{4}\sqrt{(5.04^2 - 4.8^2)(0.94^2 - 0.7^2)} = 107108.7N = 107.1KN$$

The load W per 1m perimeter, at the junction of the cone with the cylinder is given by

$$W = \frac{768286 + 107108.7 + 247686.35}{\pi * 4.8} = 74476.62\frac{N}{m} = 74.47\ KN/m$$

$$Meridional\ Tension\ (T_m) = W * cosec\alpha = 74476.62\ * cosec65 = 82175.8\frac{N}{m}$$

$$= 82.17\frac{KN}{m}$$

$$p_{n=}p_v cos^2\alpha + p_h sin^2\alpha + w_s cos\alpha$$

$$w_s = 0.12 * 25000 = 3000N/m^2$$

To find p_n at the mid-height , H=12.2m.

d’=2.76m

r = d’/4 = 0.69m

$K_f = 0.5$

$$p_h = \frac{w * r}{\mu'}\left[1 - e^{\frac{-\mu' K_f H}{r}}\right] = \frac{8000 * 0.69}{0.344}\left[1 - e^{\frac{-0.344*0.5*12.2}{0.69}}\right] = 16046.5(1 - e^{-3.04})$$
$$= 15278.9 N/m^2$$

$$P_v = \frac{P_h}{K_f} = \frac{15278.9}{0.5} = 30557.8 N/m^2$$

$$p_n = 30557.8 * cos^2 65 + 15278.9 * sin^2 65 + 3000 * cos65 = 19275.6 N/m^2$$

$$Hoop\ tension\ (T) = p_n * r_n$$

$$r_n = \frac{d'}{2} * cosec\alpha = 1.52m$$

$$Hoop\ tension\ (T) = 19275.6 * 1.52 = 29298.9\ N/m$$

At junction Height , H=10m.

P_h=21228.58N/m^2

P_h=42457.16N/m^2

$$p_{n=} p_v cos^2\alpha + p_h sin^2\alpha + w_s cos\alpha = 26287.5\ N/m^2$$

Hoop Tension (T) = p_n * r_n = 39957 N/m.

Conical hopper (emptying condition):

$$P_v = 26308.77 * \frac{\pi * 4.8^2}{4} = 476072.25N$$

$$W = \frac{476072.25 + 107108.7 + 247686.35}{\pi * 4.8} = 55098.59 N/m$$

$$Meridional\ Tension\ (T_m) = W * cosec\alpha = 55098.59 * cosec65 = 60794.56 N/m$$

To calculate p_n, at mid height of hopper,

H=12.2m.

$$p_h = \frac{w * r}{\mu'}\left[1 - e^{\frac{-\mu' K_e H}{r}}\right] = \frac{8000 * 0.69}{0.344}\left[1 - e^{\frac{-0.344*1*12.2}{0.69}}\right] = 16046.5(1 - e^{-6.08})$$

$$= 16009.7\ N/m^2$$

Therefore ,

$$P_v = \frac{P_h}{K_f} = \frac{16009.7}{1} = 16009.7N/m^2$$

$$p_{n=}p_v cos^2\alpha + p_h sin^2\alpha + w_s cos\alpha = 17277.5\ N/m^2$$

$$Hoop\ tension\ (T) = 17277.5 * 1.52 = 26261.88\ N/m$$

At junction, i.e at H=10m

P_h= 26308.77N/m^2

P_v= 26308.77N/m^2

$$p_{n=}p_v cos^2\alpha + p_h sin^2\alpha + w_s cos\alpha = 27576.62N/m$$

$$Hoop\ tension\ (T) = 27576.62 * 1.52 = 41916.47\ N/m$$

Taking the maximum value of T_m and T

T_m=82175.86 N/m

$$A_s = \frac{82175.86}{115} = 714.57\ mm^2$$

Using 12mm Ø bars,

$$Spacing = \frac{\frac{\pi * 12^2}{4} * 1000}{714.57} = 158.27 \approx 150mm$$

Providing 10mm Ø bars @ 110mm c/c .

Half of the bar may be stopped half way.

T=41916.47 N/m

$$A_s = \frac{41916.47}{115} = 364.5\ mm^2$$

Using 10mm Ø bars,

$$Spacing = \frac{\frac{\pi * 10^2}{4} * 1000}{364.5} = 203mm \approx 200\ mm$$

Providing 10mm Ø bars @ 200mm c/c

6.1.5 Ring Beam

Provide 250mm*250mm section with 4 bars of 20mm Ø and 16mm Ø 2-legged stirrups .

Provide a top rib of size 250mm*250mm section with 4bars of 12mm Ø and 12mm Ø 2-legged stirrups

The details of reinforcement etc. are shown in the AutoCad sheet (Figure 6-4).

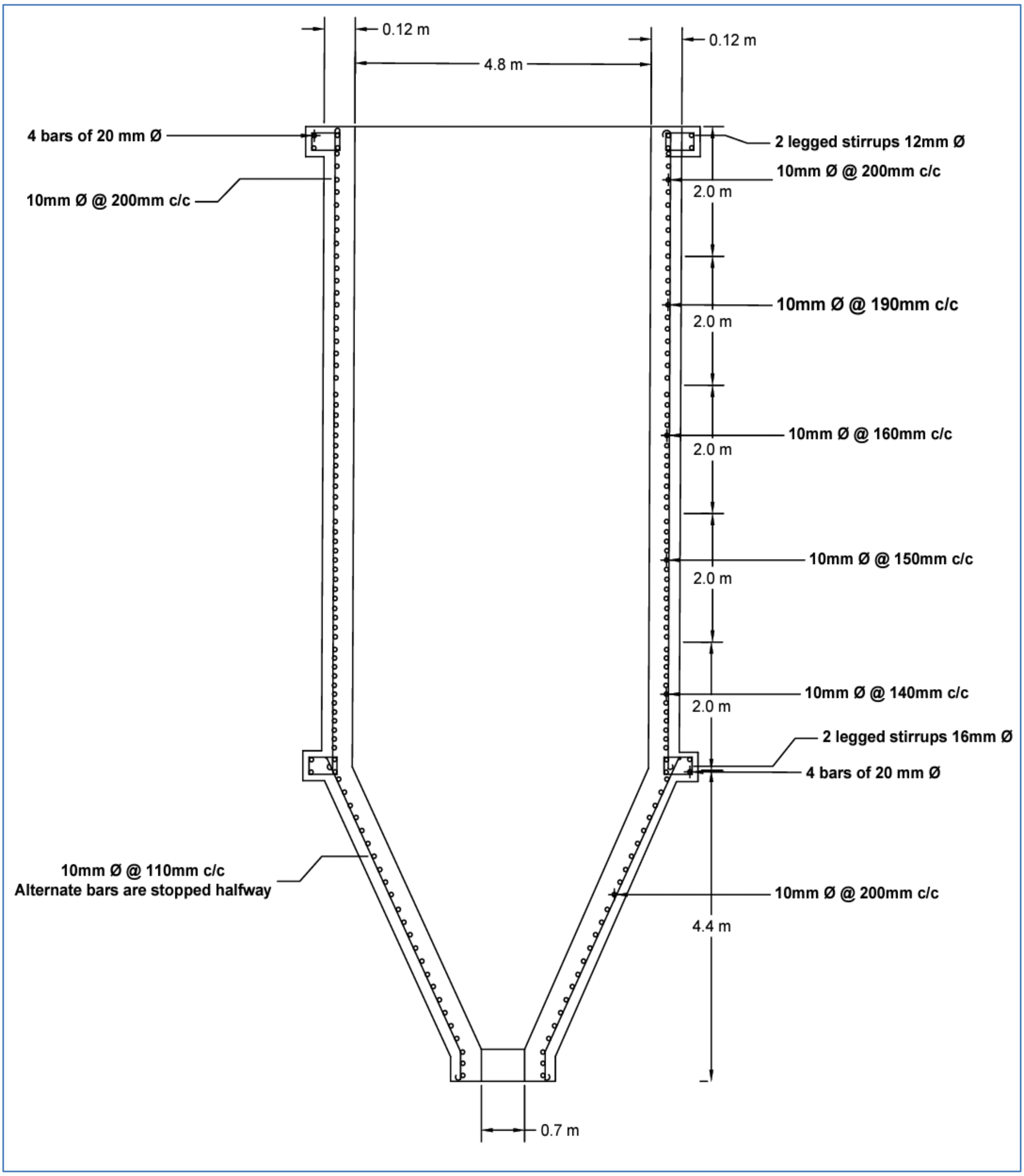


Figure 6-4 Longitudinal Section of the Silo

REFERENCES

1. Airy, W. "The Pressure Of Grain Minutes And Proceedings." Inst. Civil Engg Vol. 131 (1897): 347-358.
2. Newton R.H. , GS Dunam , JP Simpsons - "The catalytic cracking process" The Oil And And Journal (1945).
3. FC Franklin, LN Johanson – "Flow Of Granular Material Through A Circular Orifice" Chemical Engineering science 4.3 (1955).
4. RT Fowler, JR Glastonbury –"The Flow Of Granular Solids Through Oifice", Chemical Engineering Science 10.2 (1959).
5. Jenike, Andrew W. "Steady Gravity Flow Of Frictional Cohesive Solids." Flow and Storage of Bulk Solids 53.26 (1964).
6. Johanson, LN. "Gravity Flow Of Granular Material In Conical Hoppers." journal Of Applied Mechanics 46.3 (1965): 529-535.
7. J. Bosley, C. Schofield , C.A. Shook - "Study Of Granular Discharge From model Hoppers". Chemical Engineering Research and Design 47 (1969).
8. IS 4995 Part-1 "General Requirements and Assessment of Bin Loads".
9. IS 4995 Part-2 "Criteria for Design of Reinforced Concrete Bins for Storage of Granular and Powdery Materials ",1974.
10. IS 875 Part-3 "Code of Practice for Design Loads", 1987.
11. Benink, E.J. "Flow And Stress Analysis of Cohesionless Bulk Materials In Silos." (1989).
12. BC Punmia , AK Jain , AK Jain- Reinforced Concrete Structures. Laxmi Publications, 1992.
13. ACI Committee 313, "Bin wall Design And Construction" ACI Journal (1997).
14. IS 456:2000 " Plain and Reinforced Concrete – Code of Practice".
15. Chase, George C. " Solid Notes." University of Akron (2005).
16. IS 3370 Part 1 " Concrete Structures for Storage of Liquids- Code of Practice".
17. Schulze, Dietmar. "Stress in Silos".

ACKNOWLEDGEMENT

We deeply express our sincere thanks to our Director Dr. Abdul Razak Honnutagi and our Head of Department Dr. Rajendra Magar for encouraging and allowing us to conduct the project on the topic “Comparative Study Of Design Aspects And Construction Practices Of Silos” at our department premises for the partial fulfilment of the requirements leading to the award of Bachelor of Engineering degree.

It is our privilege to express our sincerest regards to our project guide, Dr. Abdul Razzak Honnutagi and Co-guide, Prof. Rohan Dasgupta for their valuable inputs, able guidance, encouragement, whole-hearted cooperation and constructive criticism throughout the duration of our project.

We take this opportunity to thank all our professors and non-teaching staffs who have directly or indirectly helped in our project. We pay our respects and love to our parents and all other family members and friends for their love and encouragement throughout our career. Last but not the least we express our thanks to our friends for their cooperation and support.