“In the name of Allah, the Beneficent, the Merciful”

A TO Z
IN
CEMENT INDUSTRY

UNIT FOUR
Bins & Feeders

4.0 Bins & Feeders

Bins have been considered for too long time as unimportant and cheep equipment when compared to mill and kiln systems. They have been considered to be simple containments only which are required to be fed with product for storage with the aim that this product may be reclaimed later at a given time at a consistent rate. The physical product characteristics have typically been ignored in bin design with exception of the angle of repose which may have been considered by using slightly steeper wall inclination for a bin’s discharge hopper. Making optimum use of a given area was the prime design criteria. So it is not surprising that operation of many bin installations is still impaired by too flat concrete discharge hoppers designed with a too small outlet and equipped with inappropriate feeders. Operation problems as erratic or even interrupted product flow out of bins with cohesive bulk solids, flushing of the feeders with powders, product segregation, and incomplete emptying resulting in a reduced bin live capacity are common experience and very often accepted to be inevitable. The use of a sledge hammer and poke rods are well known but ineffective means to compensate for the adverse consequences of a careless and incompetent bin design. It has to be mentioned that the attitude of the cement industry towards bin design has changed fundamentally in last fifteen years. Modern test procedures (as the shear test) and design concepts (mass-flow) are no longer ignored but accepted.

The bin size and geometry depend on the functional requirements such as the storage volume and the method and rate of discharge, the properties of the stored material, available space and economic considerations. Bins usually consist of a vertical sided section with a flat bottom or a bottom with inclined sides, known as the hopper (fig-4.1). They are usually circular, square or rectangular in cross-section and may be arranged singly or in groups. Circular bins are more efficient structures than square or rectangular bins, leading to lower material costs. For the same height, a square bin provides 27% more storage than a circular bin whose diameter equals the length of the side of the square bin. Flat-bottom bins require less height for a given volume of stored material.
The bin size is determined by feeding and discharge rates and the maximum quantity of material to be stored. High discharge rates require deep hoppers with steep walls. Flat bottomed bins usually have low discharge rates and are used when the storage time is long, the discharge is infrequent and the storage volume is high.
The ratio of bin height to diameter influences the loads from the stored material and hence the structural design. Eurocode-1 ["Basis of design and actions on structures, Part 4, Actions in silos and tanks", ENV 1991-4, CEN] classifies bins as either squat or slender. Squat bins are defined as those where the height does not exceed 1.5 times the diameter or smallest side length. Slender bins have a height to diameter ratio greater than 1.5.

Hoppers are usually conical, pyramidal or wedge shaped. Pyramidal hoppers have the advantage of being simple to manufacture although they may lead to flow problems due to the building up of stored material

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in the corners. Outlets may be either concentric or eccentric to the centre of the bin. Eccentric outlets should be avoided because the pressure distribution is difficult to predict and there may be problems due to segregation of the stored material. The angle of inclination of the hopper sides is selected to ensure continuous discharge with the required flow pattern.

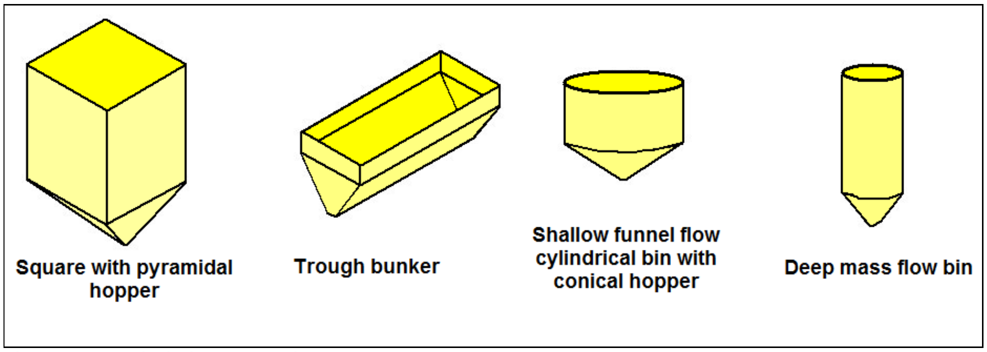

Figure-4.1: Typical Bin Geometries

It became evident that the flow pattern can be classified into two type, funnel-flow and mass-flow. These two different modes of flow (fig-4.2) can be observed if a bulk solid is discharged from a silo. In case of mass flow (fig-4.3 a), the whole contents of the silo are in motion at discharge. Mass flow is only possible if the hopper walls are sufficiently steep and/or smooth and the bulk solid is discharged across the whole outlet opening. If a hopper wall is too flat or too rough, funnel flow will appear. In case of funnel flow (fig-4.3 b) only that bulk solid is in motion first, which is placed in the area more or less above the outlet. The bulk solid adjacent to the hopper walls remains at rest and is called “dead” or “stagnant” zone. This bulk solid can be discharged only when the silo is emptied completely. The dead zones can reach the surface of the bulk solid filling so that funnel flow becomes obviously when observing the surface. It is possible as well that the dead zones are located only in the lower part of the silo so that funnel flow cannot be recognised by observing the surface of the silo filling.

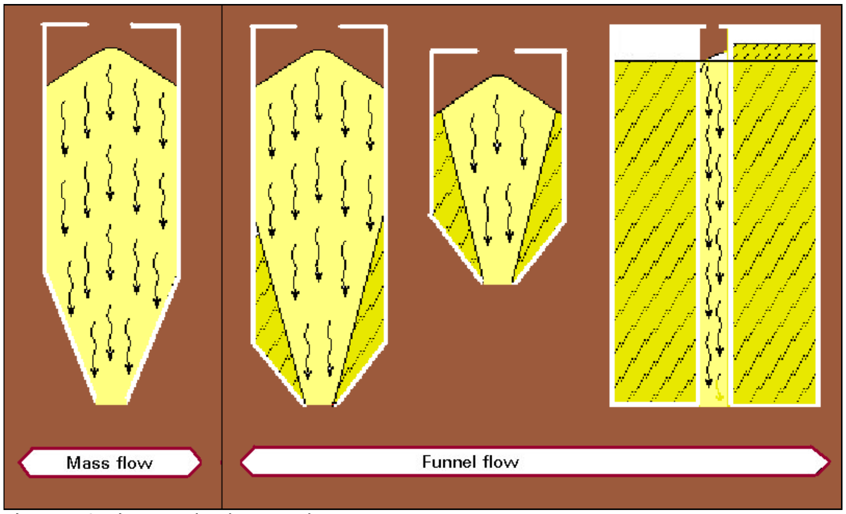

Figure-4.2: Flow Modes (Patterns)

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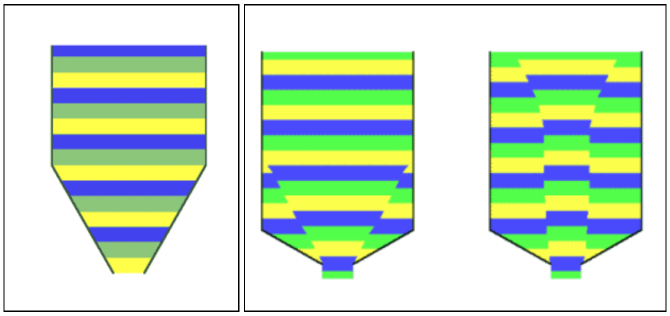

(a) (b)

Figure-4.3: (a) Mass Flow & (b) Funnel Flow

4.1 Flow Modes

There are two primary and distinct types of flow of solids in hoppers, mass flow and funnel flow. There is also a special case that is a combination of these two flows called expanded flow. These flows get their names from the way in which solids move in the hoppers.

The characteristics and differences between the three modes of flows (funnel, mass, and expanded0 are depicted below.

4.1.1 Funnel Flow

The type of flow (fig-4.4) where part of the product in the silo is at rest (stagnant zones) is called funnel flow or core flow. Funnel flow is only applicable for coarse (free flowing products) where ageing or decay is not important. In all other cases mass flow should occur.

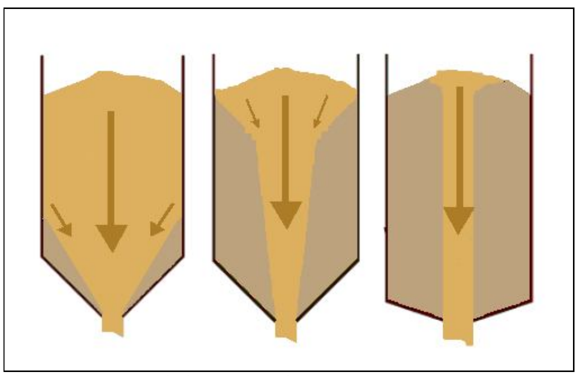

Figure-4.4: Funnel Flow Type Bin

When filling a bin, product will always segregate: The coarse grains will roll down the slope of the surface pile to the bin's circumference while the fines will predominantly be accumulated in the bin's center. Development of the flow pattern in funnel-flow type bins depends on the product's flow characteristics, the relation of feed rate versus discharge rate and the arrangement of the feed relative to the discharge opening. When opening the outlet of a funnel-flow type bin product will flow in a narrow core only that forms just above the bin's outlet while the surrounding product remains at rest. Bulk solid discharge is essentially irregular regarding rate and density. Funnel-flow type bins can typically not be emptied completely what results in a reduced live capacity. The discharge order is inverted compared to the loading order, i.e. the bin shows a first-in last-out flow sequence.

For no feed conditions, the product that will be discharged first is the fine product from the bin center zone. Product surface will then be inverted from a pile to a funnel shape; product level in the bin will fall. With the coarse particles from the bin's circumference now rolling down the slope to the center, granulometry of the discharged product changes from fine to coarse. The entire product surrounding the

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center core remains at rest. The discharge order is inverted compared to the loading order, i.e. the bin shows a first-in last-out flow sequence.
In case the feed rate is larger than the discharge rate product level in the bin is rising, the product surface keeps a pile shape and the product's fine portion is predominately discharged as all the coarse particles roll down the pile slope. The entire product surrounding the center core remains at rest.
In cases that feed rate and discharge rate are similar, product level in the bin and shape of product surface will remain constant. Product does not segregate on feeding as it passes directly to the bin outlet via the activated center core. Again all the product surrounding the center core remains at rest. (Figure-4.5) shows a variety of designs for funnel flow hoppers.

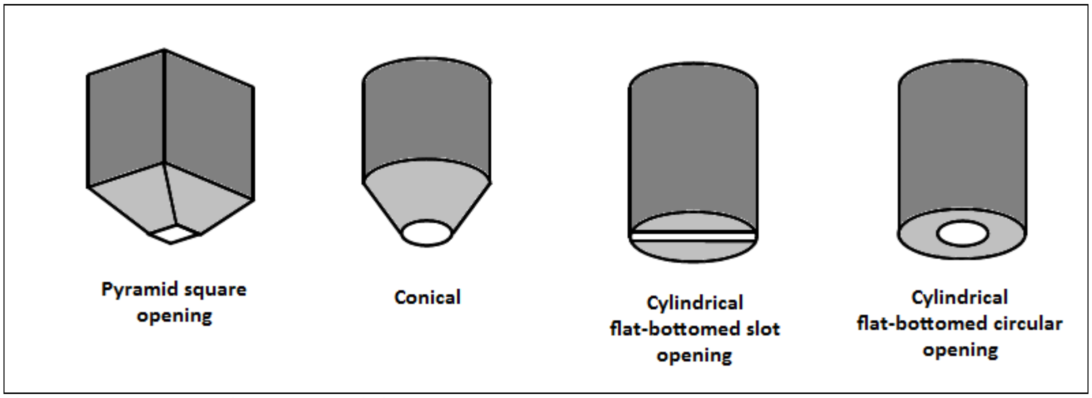

Figure-4.5: Common Designs for Funnel Flow Hoppers

Funnel-flow can be evaluated as the following:
a) Maximized storage volume for given headroom but only in case the bin volume may be cleared completely on a batch wise basis.
b) Low investment per m^3 storage volume.
c) Tends to erratic flow and an inconsistent discharge rate (inconsistent regarding flow rate and bulk density).
d) First-in last-out flow sequence.
e) Varying product quality at bin discharge as product segregation on feeding is not corrected.
f) Non-flowing zones favouring product degradation with time resulting in spoiling, lump formation, wall hang-ups and loss of live capacity due to incomplete emptying.
g) Subject to flow stoppages if the product consolidates (packs) sufficiently to form stable arches or rat-holes.
h) Funnel-flow may be acceptable in cases:
1) Where segregation is unimportant.
2) Where product degradation is not likely to be a problem.
3) Where feed rate consistency is not of prime importance.

4.1.2 Mass Flow

Typical characteristics of mass-flow bins are slender shape, steep wall slopes of the discharge hopper and relatively large outlets. Typical mass-flow type bin shapes are shown in (fig-4.6).

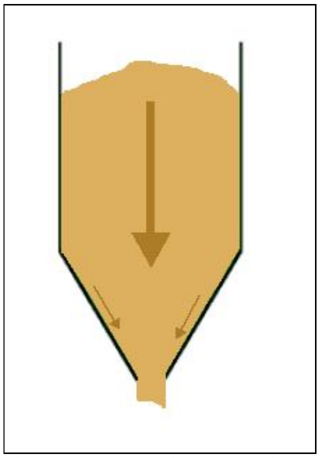

Figure-4.6: Mass Flow Type Bin

Product segregation when filling a mass-flow type bin cannot be prevented with the coarse grains rolling down the piles slope to the bin circumference while the fines will predominately be accumulated in the bin center. The flow pattern that develops in a mass-flow type bin differs from that of a funnel-flow type bin considerably. In mass-flow type bins all the stored product is activated and moves towards the bin outlet whenever product is discharged. This results in a first-in first-out flow pattern. Mass-flow type bins can typically be emptied completely at uniform discharge rate. (Figure-4.7) shows some of the more common designs found for mass flow hoppers.

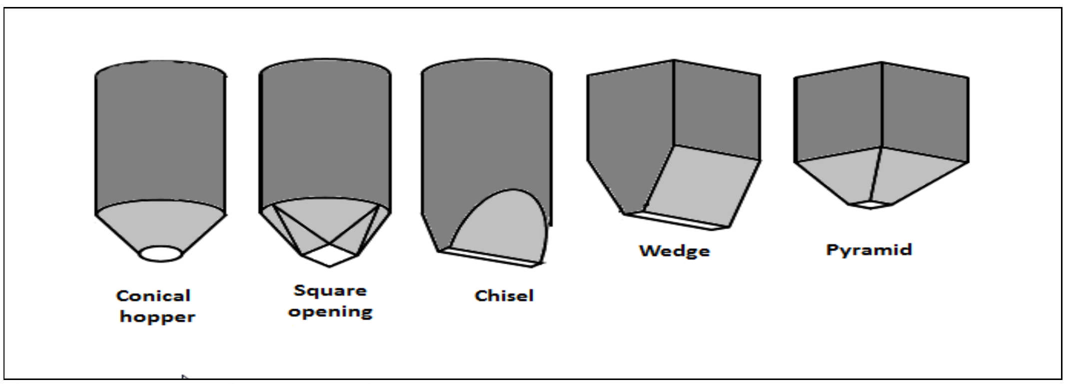

Figure-4.7: Common Designs for Mass Flow Hoppers

Mass-flow can be evaluated as the following:

a) Product flow out of the bin is uniform independent of the head of product in the bin, erratic flow and flushing is absent.

b) First-in first-out flow sequence preventing product deterioration due to excessive storage at rest periods.

c) Remixing effect for products which segregate on feeding.

d) High investment per m^3 storage volume.

e) Non-flowing zones are absent as formation of product lumps and wall hang –ups.

f) Mass-flow type bins should always be selected in cases:

1) Where segregation is important.
2) Where product degradation is a problem.
3) Where feed rate consistency is of prime importance (e.g. for feed bins).

4.1.3 Expanded Flow

The typical shape of an expanded-flow type bin is shown in (fig-4.8). From this figure the concept becomes evident: The selected bin discharge configuration is that of a composite hopper with the upper hopper section designed for funnel-flow and the lower section for mass-flow.

It is evident that the expanded-flow concept combines both the funnel-flow and the mass-flow pattern. This is a creative way of increasing a bin's storage capacity while ensuring consistent product discharge. In general, the expanded flow concept is used for large storage facilities such as stockpiles and multi-outlet silos and bins.

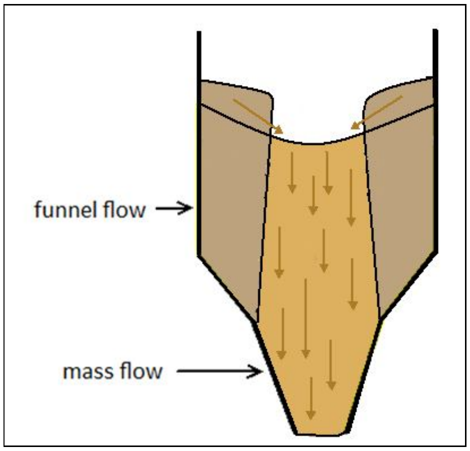

Figure-4.8: Expanded Flow Pattern

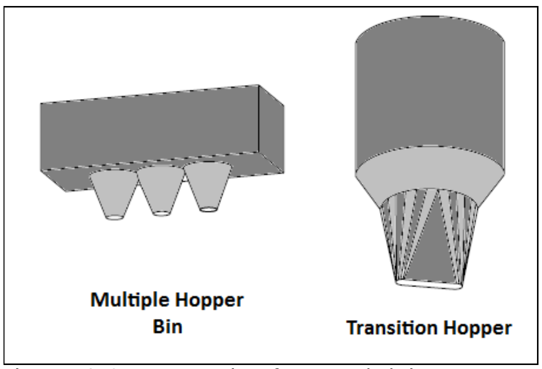

Figure-4.9: Common Designs for Expanded Flow Hoppers

Expanded flow can be evaluated as the following:

a) Optimized storage volume for a given headroom.
b) Relatively low investment per m^3 storage volume.
c) Product flow out of the bins is uniform.
d) Partial remixing effect for products which segregate on feeding.
e) Last-in first-out flow sequence.
f) Non-flowing zones favouring product degradation with time.
g) Expanded-flow may be useful:
  1) Where segregation is unimportant.
  2) Where product degradation is not likely to be a problem.
  3) As a means to improve the insufficient flow pattern of a given bin.

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4.2 Problems Associated with Bulk Solids Flow & Hopper Design

Bulk solids flow and hopper design problems are normally one of two types; either the material does not discharge adequately from the opening in the hopper or the material segregates during the flow. These problems which are summarized below have a variety of effects on a particular process that can result in quality problems, lost production, Product spoilage, structural damage, personnel injuries and wasted time and money.

4.2.1 Arching

Arching (fig-4.10) occurs when an obstruction in the shape of an arch or a bridge forms above the outlet of a bin and prevents any further discharge. It can be an interlocking arch, where the particles mechanically lock to form the obstruction, or a cohesive arch. An interlocking arch (fig-4.11 a) occurs when the particles are large compared to the outlet size of the hopper. A cohesive arch (fig-4.11 b) occurs when particle-to-particle bonds form, allowing the material to pack together to form an obstruction.

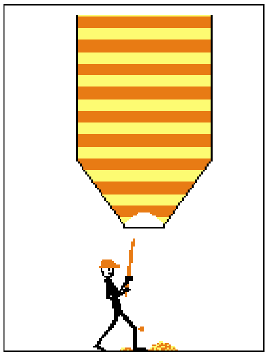

Figure-4.10: Arching

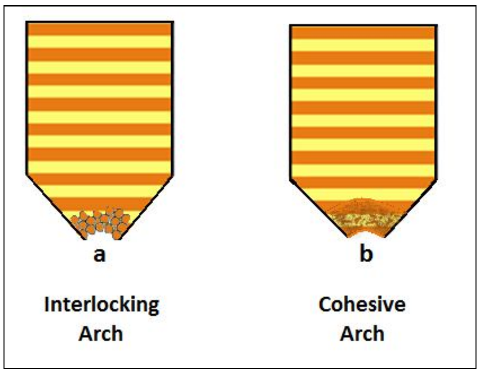

Figure-4.11: Interlocking & Cohesive Arch

4.2.2 Rat-holing or Piping:

Rat-holing (fig-4.12) occurs in case of funnel flow if only the bulk solid above the outlet is flowing out, and the remaining bulk solid (the dead zones) keeps on its place and forms the rat-hole or pipe. The reason for this is the strength (unconfined yield strength) of the bulk solid. If the bulk solid consolidates increasingly with increasing period of storage at rest, the risk of rat-holing increases. If a funnel flow silo is not emptied completely in sufficiently small regular time intervals, the period of storage at rest can become very large thus causing a strong time consolidation.

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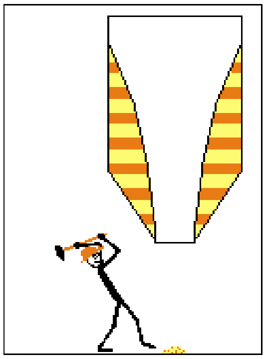

Figure-4.12: Rat-holing

4.2.3 Erratic Flow

Erratic flow is often the result of an obstruction alternating between an arch and a rat-hole (fig-4.13). A rat-hole may fail due to an external force, such as ambient plant vibrations, vibrations created by a passing train, or vibrations from a flow aid device such as an air cannon, vibrator, etc. While some material may discharge as the rat-hole collapses, falling material often gets compacted over the outlet and forms an arch. This arch may break due to a similar external force; and material flow resumes until the flow channel is emptied and a rat-hole form again.

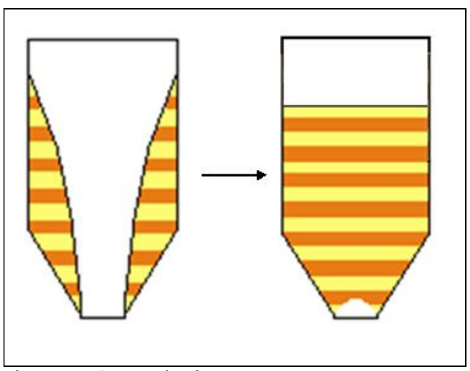

Figure-4.13: Erratic Flow

4.2.4 Wide Residence Time Distribution

If dead zones are formed (funnel flow), the bulk solid in this zones is discharged only at the complete emptying of the silo, whereas bulk solid, which is filled in later, but located closer to the axis of the silo, is discharged earlier. Because of that, a wide distribution of residence time appears which is disadvantageous in some cases (e.g. in case of storage of food or other products changing their properties with time).

4.2.5 Segregation

If a heap is formed on the bulk solids' surface at filling of the silo, segregation is possible according to particle size or particle density (fig-4.14). In case of centric filling as shown in the (fig-4.15), the larger particles accumulate close to the silo walls while the smaller particles collect in the centre. In case of funnel flow, the finer particles which are placed close to the centre are discharged first while the coarser particles are discharged at the end. If such a silo is used, for example as a buffer for a packing machine, this behaviour will yield to different particle size distributions in each packing. In case of a mass flow, the bulk solid will segregate at filling in the same manner, but it will become "remixed" when flowing downwards in the hopper. Therewith, at mass flow the segregation effect described above is reduced significantly.

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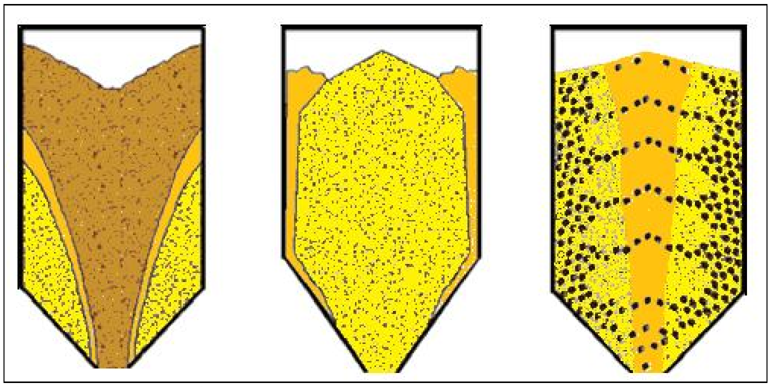

Figure-4.14: Segregation Patterns Due to Different Mechanisms

Figure-4.15: Segregation

4.2.6 Flushing or Flooding

Fines powders become aerated and discharge uncontrollably from the bin, behaviour like liquid. This can happen when a rat-hole collapses allowing the solids to fall into the open channel under pressure (fig-4.16).

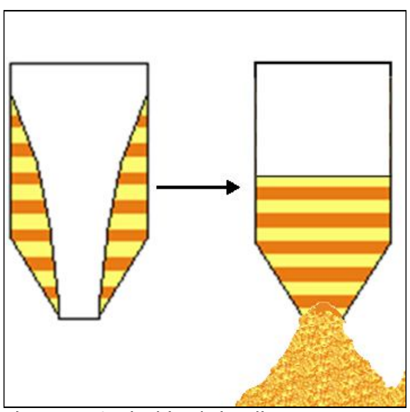

Figure-4.16: Flushing/ Flooding

In a funnel flow silo, all problems mentioned above can occur generally, while in case of mass flow only arching has to be considered. Segregation, rat-holing, irregular flow and flooding of the bulk solid do not appear in a well designed mass flow silo. The residence time distribution of a mass flow silo is narrow, because it acts as a “first in - first out” system.

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4.2.7 Caking

Another important effect is called caking. Caking refers to the physiochemical bonding between particles what occurs 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.

Many of the problems associated with bin and hopper design can be avoided by designing the hopper to operate in mass flow mode. The required cone angle from the vertical axis for mass flow to occur; ranges from 40° to 0°. But mass flow is not necessary in all cases. In some situations a mass flow hopper design is not practical due to the head room required.

4.3 Natural of Bulk Solids

A bulk solid consists essentially of a multitude of granules (particles) which are randomly grouped to form of a bulk. These granules differ in size, shape, hardness, surface texture, chemical composition, and etc. The nature of a bulk solid not only depends on the characteristics of its constituent particles but also on factors as its way to compact and get strength i.e. its cohesion, angle of repose, tendency to adhesion, wall friction, the influence of moisture and storage at rest.

Hence it follows that any characterization of bulk solids must consider two levels, the features of the constituent particles and the features describing a products bulk form. Unfortunately nowadays level of knowledge is still not sufficient as to allow for a reliable prediction of a bulk solids behaviour based solely on the characteristics of its constituent particles.

A first step in the characterization of bulk solids is always a qualitative description of its behaviour. Questions to be asked are: does it flow easily or is it sticky? And is it fragile, abrasive, corrosive, or explosive? Such descriptive terms are essential when communicating information on bulk solids. But they are unlikely sufficient as to allow for the design of handling systems which are matched to the product. For this purpose measurable numerical parameters are required which characterize a bulk solid in a quantitative manner.

The most important characteristics relevant to bulk solids can be summarized as:

4.3.1 Particle Size & Particle Size Distribution (Granulometry)

Qualitative terms commonly used to describe the granulometry of a bulk solid are given in (table-4.1).

Descriptive term	Particle Size Range	Example
Coarse (crushed) Solid	5 - 300 mm	Limestone
Granular Solid	0.3 - 5 mm	Sand
Particulate Solid:		
- Coarse Powder	100 - 300 mm	Separator Grits
- Fine Powder	10 - 100 mm	Cement
- Superfine Powder	1 - 10 mm	Dust Collector Product
- Ultrafine Powder	< 1 mm	Paint Pigments

Table-4.1: Descriptive Terms for Bulk Solid Granulometry

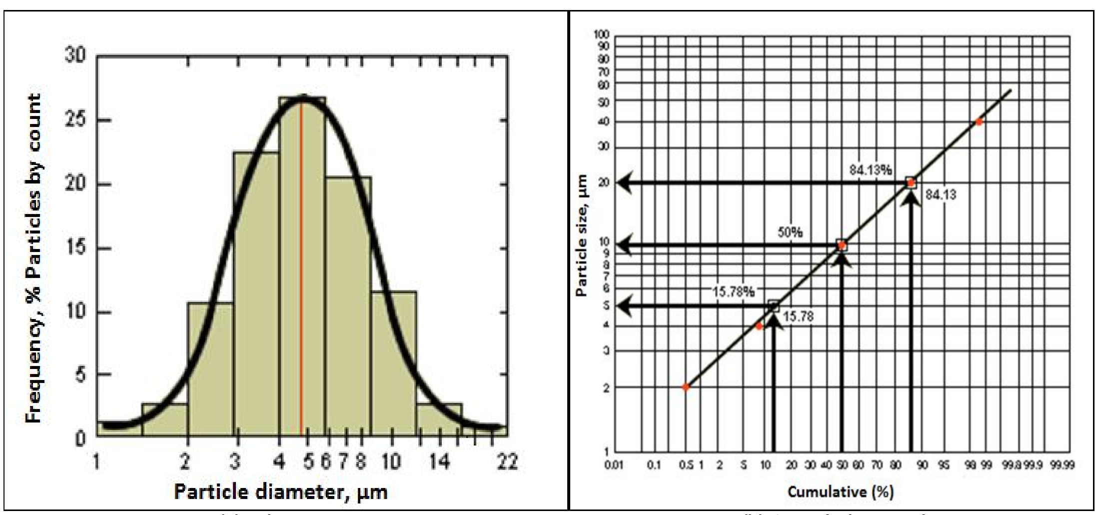
Above qualitative terms are not sufficiently precise for the description of conglomerates of irregularly shaped and sized particles. Quantitative parameters are required for the description of particle size, size distribution, and shape.

Monosized spherical particles are easy to be described, because one single dimension is required but for a conglomerate of spherical particles of varying sizes the situation is more complex. For the characterization of particle size distribution, the definition of an average particle diameter is required together with some information on particle size distribution. The situation gets worse in case of industrial non-spherical bulk solids. The parameters used for the description of particle size, size distribution and shape need careful definition. It is a common industrial practice to determine the granulometry of bulk solids by using one of the sizing techniques given below in (table-4.2). The selection of the sizing technique depends on the product's particle size range.

Sizing Technique (Method)	Useful Range (approx.)
Sieving:	
Dry	50 µm - 100 mm
Wet	10 µm - 100 mm
Electrical sensing zone (Coulter counter)	1 µm - 800 µm
Laser diffraction spectrometry	1 µm - 200 µm
Sedimentation & elutriation	2 µm - 75 µm
Optical microscopy	1 µm - 150 µm
Electron microscopy	0.01 µm – 1 µm

Table-4.2: Some Familiar Methods of Size Analysis & Their Range of Application

The most popular (and cheapest) method of particle size analysis, especially with relatively coarse materials, is sieving. The results of a sieving test can easily be represented in a histogram (Fig-4.17a), i.e. by drawing rectangles over the selected class intervals. The area of each rectangle is proportional to the percentage of particles in that class. A smooth curve through the intervals, results in a grain size distribution curve.
An even more useful way for the representation of the analysis data is the cumulative graph (Fig-4.17b). In such a graph the particle size is represented along the vertical axis whereas the cumulative percentage retained or passing is given on the horizontal axis. The advantage of this representation is that grain sizes not determined experimentally are reliably predicted as is the median particle size (the 50% size). The median particle size mentioned above is probably the most common term used for representing a bulk solids average particle size.
This both mentioned method which is used for characterization of a bulk solid's granulometry depends on the product's industrial use. The median is common in cement industry for characterization of e.g. raw meal and cements.



(a) Histogram (b) Cumulative graph

Figure-4.17: Graphical methods of presenting particle size distribution

4.3.2 Particle Shape

The shape of the particles of a bulk solid has proven to be relevant for its packing and flow behaviour. But establishing quantitative data on particle shape is discouraging as there is hardly an agreement on how to define shape factors.

For the time being the effect of particle shape on a bulk solid's flow behaviour can only be based on qualitative observations:

a) Fibrous appearance may warn of a tendency to particles interlocking,

b) Sharp angular particle shape may indicate that abrasive wear may be excessive.

4.3.3 Particle Hardness

A knowledge of the hardness of the particles constituting a bulk solid is valuable when a handling installation is being designed since it will give an indication of the need to take steps to avoid undue erosive wear of the system components. Generally speaking, the harder the particles, the more abrasive the product will be on the materials from which the handling installation is constructed.

In 1822 a semi-quantitative 'scale of hardness' (table-4.3) was first proposed by Mohs, who selected ten mineral standards beginning with the softest, talc (Mohs hardness 1), and ending with the hardest, diamond (Mohs hardness 10).

The scale goes from 1 to 10, Diamond is at the top of the scale with a rating of 10, and Talc is the softest with a rating of 1. You can use minerals of known hardness to determine the relative hardness of any other mineral. A mineral of a given hardness will scratch a mineral of a lower number. For example one of your finger nail (2) can scratch a talc (1) specimen or with a broken glass (5) you can scratch a calcite (3) or fluorite (4) specimen. To use the hardness scale, try to scratch the surface of an unknown sample with a mineral or substance from the hardness scale (these are known samples). If the unknown sample cannot be scratched by calcite (3) but it can be scratched by fluorite (4), then its hardness is between 3 and 4. An example of minerals that have hardness between 3 and 4 are barite, celestite and cerussite (3 to 3.5).

Mohs scale hardness	Material	Chemical formula	Scratch test
1	Talc	$Mg_3(OH)_2{\cdot}(Si_2O_5)_2$	Very soft, can be powdered with fingers
2	Gypsum	$CaSO_4{\cdot}2H_2O$	Moderately soft, can scratch lead
3	Calcite	$CaCO_3$	Can scratch finger nail
4	Fluorite	CaF_2	Can scratch a copper coin
5	Apatite	$Ca_5(PO_4)_3(Cl, F)$	Can scratch a knife blade with difficulty
6	Feldspar	$KAlSi_3O_8$	Can scratch a knife blade
7	Quartz	SiO_2	All products harder than 6 will scratch window glass
8	Topaz	$Al_2F_2SiO_4$	
9	Corundum	Al_2O_3	
10	Diamond	C	

Table-4.3: Mohs Scale of Hardness

4.3.4 Voidage & Bulk Density

The shape of particles constituting a bulk solid obviously depends upon the manner of their production but, irrespective of whether they are of regular or irregular shape, when they are packed together in random orientation there will be a certain amount of free space between them. Thus a bulk solid is really a combination of particles and space, the percentage of the total volume not occupied by the particles usually being referred to as the 'voidage' or 'void fraction'.

Voidage (ξ) = $[V_{voids} / (V_{particles} + V_{voids})] * 100$ [%]

Where;

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$V_{voids:}$ Volume of voids
$V_{particles}$: Volume of particles

In a bed of material having unit volume, the actual volume of solid particles or 'fractional solids content' is (1- ξ). Sometimes the term 'porosity' is applied to bulk to means the same as 'voidage'. However, it is probably advisable to reserve this term as a description of the structure of individual constituent particles. Thus we can define the particle porosity as the ratio of the volume of pores within a particle to the volume of the particle (inclusive of pores).

Typical values of the voidage in static bulk materials consisting of monosized spheres would range from 0.26 (that is 26%) for regular hexagonal packing, to 0.48 for regular cubic packing (fig-4.18).

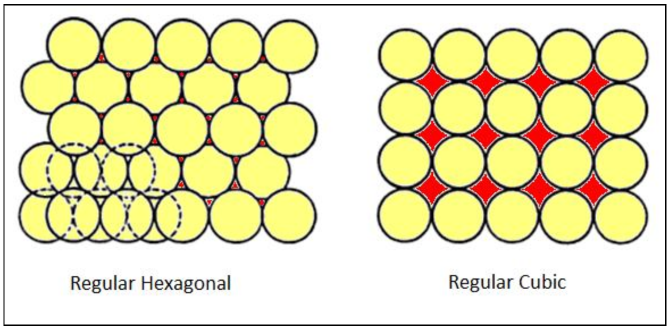

Figure-4.18: Packing Arrangement for Monosized Spheres

For closely graded irregular particles in random packing arrangements the voidage would normally lie between these extremes, a high voidage corresponding to a loose packing. A reasonable average figure would be around 0.4 for spheroidal particles, but where a material consists of particles of extremely irregular shape, especially if they are also of very small size (i.e. fine cohesive products), the voidage could be much higher.

A quantity of particulate or granular material will have an apparent density, usually termed 'bulk density' which can be defined as the mass of the material divided by its total volume (particles & voids).

Bulk Density (ρ_b) = $[(m_{solids}+m_{voids})/(V_{solids}+V_{voids})]$ [t/ m^3]

Where;
m_{solids} : Mass of solid particles
m_{voids}: Mass of voids

Writing ρ_p as the 'true' density of the solid particles and ρ_f as the density of the fluid in the void spaces, it can be shown that an expression for the bulk density is:

$\rho_b = (\rho_p - \rho_f)(1-\xi) + \rho_f$

For dry bulk solids the density ρ_f would be negligible compared with ρ_p so that the relationship between bulk density and particle density becomes:

$\rho_b = \rho_p(1-\xi)$

Clearly knowledge of the bulk density of a product is essential in order to design storage vessels, conveying systems and the like. Determination of this parameter from sample of the material concerned involves measurement of the mass of the sample and its total volume.

4.3.5 Angle of Repose

When a quantity of bulk solid is allowed to form a heap, or when slippage of material occurs so that a sloping surface is exhibited, the angle of the free surface may take any value up to some maximum which depends principally upon the nature of the bulk solid concerned (fig-4.19/1). To some extend the value of this maximum angle also depends upon the way that the sloping surface is formed, but with a standardized test procedure it is found to be reasonably consistent for a given bulk solid. Thus it is possible to define an ‘angle of repose’ as the limiting natural slope of the free surface of a bulk solid observed during a specified test procedure, and this can be regarded as a property of the material concerned.

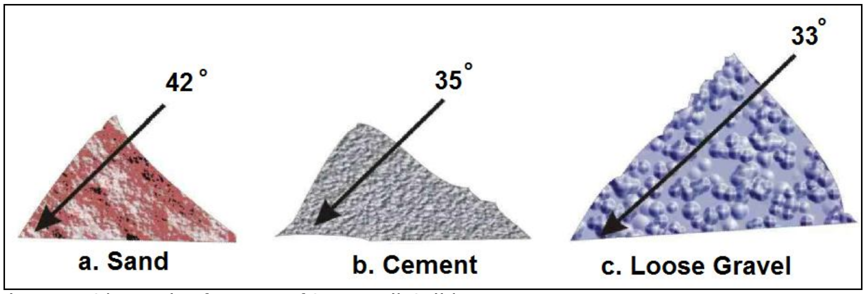

Figure-4.19/1: Angle of Repose of Some Bulk Solids

Many methods have been devised for measuring the angle of repose of bulk solids, but it is important to recognize that the value determined will depend not only upon the condition of the bulk solid (for example, its moisture content or level of electrostatic charge) but also upon the test procedure adopted and the skill of the operator. Several methods are illustrated in the figure (fig-4.19/2). The most commonly used method yields a value of ‘poured’ angle of repose, which is the angle between the horizontal and the sloping side of the a heap of the material poured gently from a funnel on to a flat surface (figure-4.19/2 a). The technique probably giving the best repeatability is that illustrated in (figure-4.19/2 f), in which a circular platform of known diameter (typically around 75mm) is supported over a circular hole in a flat base plate and surrounded by a cylinder of suitable diameter and height. After carefully filling the cylinder with the bulk solid to be tested, the operator unplugs the hole beneath the circular platform and, when flow through the hole has ceased, remove the cylinder. Measurement of the height of the cone of material remaining on the platform then allows the ‘drained’ angle of repose to be calculated.

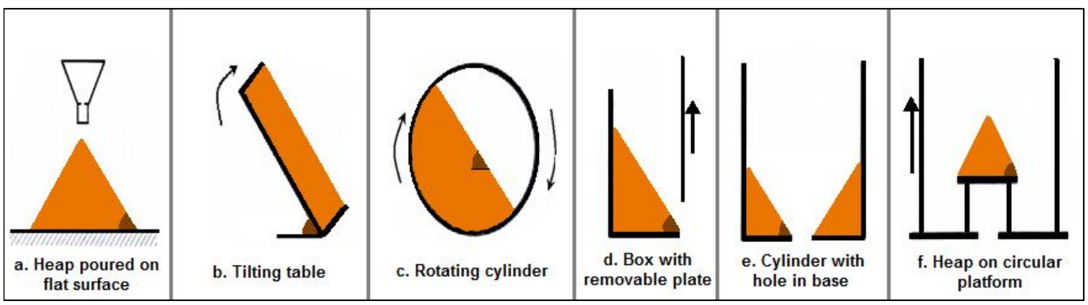

Figure-4.19/2: Methods of Measurement of Angle of Repose

It is reasonable to regard the angle of repose of a bulk solid as crude evidence of its likely flow behaviour, as follows in (table-4.4).

Angle of repose	Flow behaviour
25-30°	Very free-flowing
30-38°	Free-flowing
38-45°	Fair flowing
45-55°	Cohesive
> 55°	Very cohesive

Table-4.4: Relationship between Angle of Repose & Flowability

In fact, it is generally safer to treat angle of repose only as an indicator of the contours of heaps of the material. Thus, for example, the angle of repose of a bulk solid is required in order to determine the ullage space in hoppers or bins, the cross-section area of material transported on a belt conveyor, the surface topography of stockpiles, and so on.

4.3.6 Cohesion & Adhesion

Flowability of a bulk solid is function of the forces of attraction or the 'cohesion' between its constituent particles. In case the interparticle forces are low the bulk solid will easily flow with the single particles moving as individuals relative to one another. Dry sand and clinker is familiar examples from cement industry. However, high interparticle cohesive forces, which may be caused be moisture or electrostatic charging, and are especially pronounced in very fine materials, result in a tendency for agglomerates to form so that the material flows in an erratic manner as 'lumps', if indeed it flows at all (fig-4.20). Familiar examples for cohesive products in the cement industry are clay, natural and synthetic gypsum, fine coal, fly-ashes, etc. When cohesion is defined to be a bulk solid's resistance to shear under a given compressive (normal) stress quantitative measurement becomes possible (for details, see paragraph 'Shear Strength').

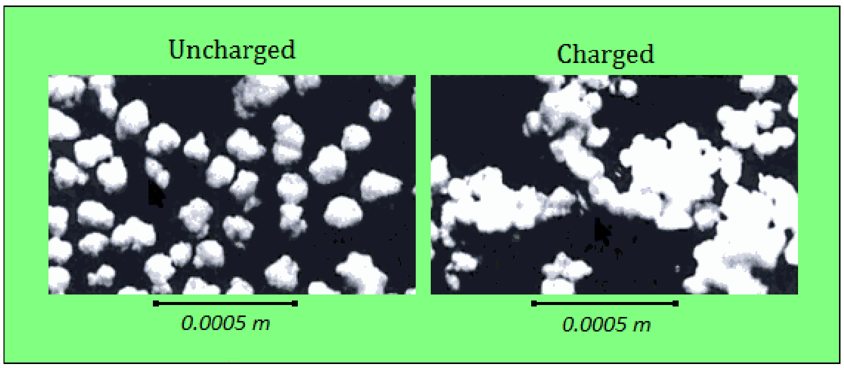

Figure-4.20: Effect of Electrostatic Charging on PVC Powder

Flowability of bulk solids is not only concerned with cohesion but also with 'adhesion' on boundary surfaces such as the walls of a bin discharge hopper, the bottom and side surfaces of transfer chutes, etc. Whereas cohesion reflects the effects of interparticle attractive forces, adhesion describes a bulk solids tendency to stick on a boundary surface. The adhesions between a bulk solid and a type of surface material can quantitatively be measured using a test similar to the shear test mentioned above for cohesion (for details, see paragraphs 'Shear Strength' & 'Wall Friction').

A measurement that is often used (incorrectly) as an indication of flow behaviour is the angle of repose' that the free surface of a bulk material takes up when the gravitational slipping occurs. Certainly, this is a convenient and usually reproducible characteristic of bulk solids, but for the determination of flow behaviour of such materials the appropriate tests are those involving the use of some kind of shear cell.

4.3.7 Shear Strength

The phrase "good flow behaviour" usually means that a powder or bulk solid flows easily. Products are "poorly flowing" if they experience flow obstructions (arches or rat hole), or consolidate during storage or transport. The reason for the latter is the compressive strength (unconfined yield strength) of a bulk solid.

(Figure-4.21) Shows a hollow cylinder with frictionless walls; filled with a fine-grained, cohesive bulk solid. First the bulk solid is consolidated by the consolidation stress σ_1 (fig-4.21 a). Subsequently the hollow cylinder is removed (fig-4.21 b) and the cylindrical bulk solid specimen is loaded with an increasing vertical compressive stress until the specimen breaks or fails (fig-4.21 c). The stress causing failure is called compressive strength or unconfined yield strength σ_c.

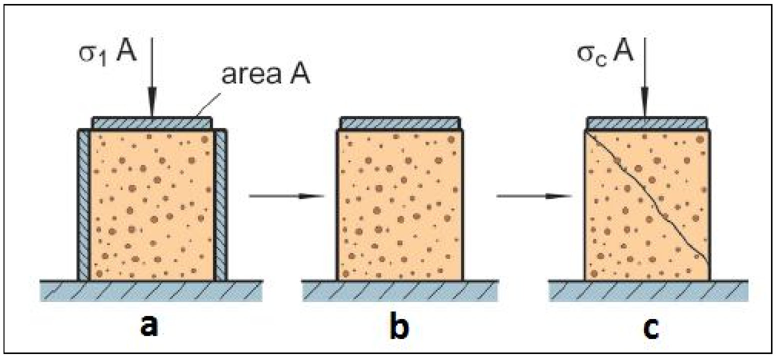

Figure-4.21: Measurement of Unconfined Yield Strength

The unconfined yield strength σ_c typically increases with consolidation stress σ_1. (Fig-4.22) shows the relationship between unconfined yield strength σ_c and consolidation stress σ_1. The ratio ff_c of consolidation stress σ_1 to unconfined yield strength σ_c is used to characterize flowability numerically:

$ff_c = \sigma_1 / \sigma_c$

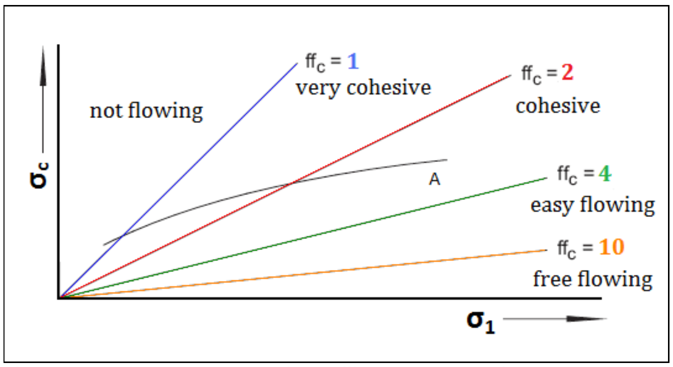

Figure-4.22: Lines of constant flowability ff_c (compressive strengthversa consolidation stress)

The larger ff_c is; the better a bulk solid flows. Often the following classification in (table-4.5) is used to determine the flowability of bulk solid:

Flowability	Flow of Bulk Solid
$ff_c < 1$	Not flowing
$1 < ff_c < 2$	Very cohesive (to non-flowing)
$2 < ff_c < 4$	Cohesive
$4 < ff_c < 10$	Easy-flowing
$10 < ff_c$	Free-flowing

Table-4.5: Bulk Solid Flowability

Additionally, in (fig-4.22) the boundaries of the ranges of the classifications listed above are shown as straight lines. The ratio ff_c and thus the flowability of a specific bulk solid change with consolidation stress σ_1. Therefore, for flowability measurements testers are required to measure the consolidation stress which is fulfilled by appropriate shear testers. Several types of shear-testing device have been proposed, some commonly used shear testers are:

a) Jenike Shear Cell Tester.

b) Carr Indices Tester.

c) Direct Shear Cell Tester.
d) Triaxial Cell Tester.
e) Ring Shear Cell Tester.
Ring Shear Cell Tester is a widely used tester in industry and research. In Ring Tester, the bulk solid specimen (fig-4.23) is contained in an annular shear cell ("ring") and loaded from the top with a vertically acting force N through the lid in order to adjust the stress level. During testing the shear cell rotates slowly in direction of arrow (ω), while the lid is prevented from rotation by two tie rods. Thereby the bulk solid specimen is sheared. Forces (F_1 +F_2) acting in the tie rods are measured. From the results of a prescribed test procedure the flow properties of the bulk solid are calculated.

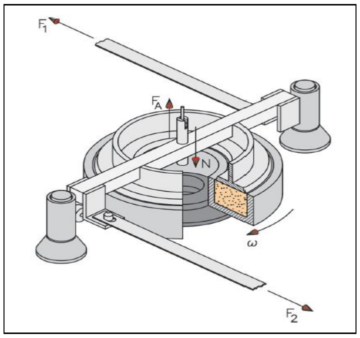

Figure-4.23: Ring Shear Cell Tester

4.3.9 Wall Friction
Wall friction is a key parameter in the design and operation of hoppers, silos, and discharge chutes. It is defined as the frictional resistance to bulk flow that exists between particles and wall material. The first step in hopper designing is to make sure that the hopper walls are sufficiently steep and smooth to force the bulk material to slide along them. The required steepness and smoothness is determined by first testing to measure wall friction and then using a set of design charts.

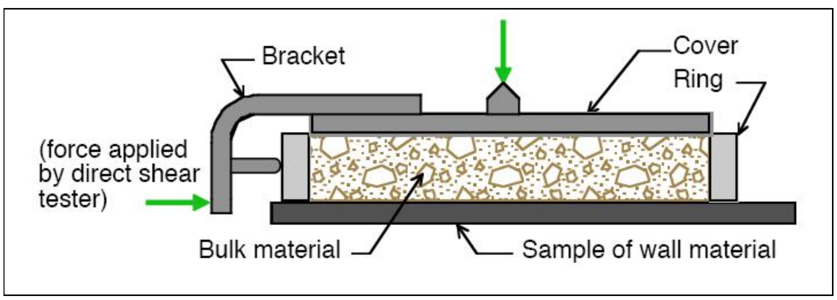

Figure-4.24: Wall Friction Measurement Test

For a bulk material to slide on a surface, friction between the two must be overcome. This friction can be measured by use of a test apparatus such as the one shown in (fig-4.24). First, the bulk material is placed in a retaining ring on a flat piece of wall material. Then, using weights, various forces are applied to the material in a direction normal (perpendicular) to the wall surface. Material in the ring is forced to slide along the stationary wall material, and the resulting shear force is measured as a function of the applied normal force.

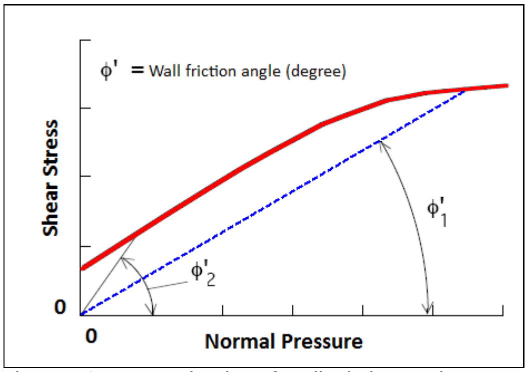

Figure-4.25: Determination of Wall Friction Angle

The figure (fig-4.25) shows the results of a typical wall friction test. Along the horizontal axis are values of normal pressure (pressure per unit area acting perpendicular to surface) applied to the material, while the vertical axis represents the measured shear stresses required to overcome friction with the wall sample. Wall friction angle (Φ′) is defined as the angle formed by a line drawn from the origin to a point on the curve. For a given bulk material and wall surface this angle is not necessarily a constant but often varies with normal pressure, usually decreasing as normal pressure increasing.

Wall friction is a complex phenomenon influenced by many factors for a given bulk material, wall friction can be affected by:

a) Wall material: Generally, the smoother the wall surface, the lower the wall friction angle. As a result, less steep hopper angle are needed to ensure mass flow.

b) Temperature: Both the wall temperature and the bulk material temperature can affect the wall friction angle that develops.

c) Moisture: Changes in moisture of the bulk material can affect wall friction angle. In some cases, moisture can migrate to the wall surface when warm material is deposited on cold bin walls.

d) Abrasive wear: As a surface wear, it often becomes polished. Thus, a design based on an unpolished surface is often conservative. In other cases, the surface becomes rougher, which can upset mass flow.

e) Time at rest: Some bulk materials adhere to wall surfaces while remaining at rest under pressure. As a result, the wall friction angle becomes larger, and steeper hopper angles are needed for mass flow.

4.3.10 Moisture Content

Product moisture can have a dramatic influence on a bulk solid's flow behaviour in addition to cause effects such as chemical change, deterioration of quality, etc. Moisture analysis is therefore an important task in characterization of bulk solids. A common expression for a bulk solid's moisture content is the percentage of water to wet solid:

Moisture Content = $[(m_{H2O})/ (m_{wet})] \times 100$ [%]

It has to be noted that water presence in bulk solids may be in two different forms, as surface water present on the surface of the particles only or as inherent moisture resulting from water being crystallized within the structure of the particles.

The most common method for determining a bulk solid's moisture content is still by determining the loss in weight for a product sample when drying it in an oven until its weight remains constant. The moisture content can then be calculated as

Moisture Content = $[(m_{wet}-m_{dry})/ (m_{wet})] \times 100$ [%]

When testing the surface moisture of bulk solids containing crystallized water in the structure of particles (e.g. gypsum, coal, etc.) the drying temperature must be selected that low that product dehydration do not occur. Recently faster analysis methods have been introduced for moisture determination such as infrared absorption, microwave absorption, nuclear magnetic resonance, ultrasonic, etc.

With regard to a bulk solid's flow behaviour commonly two moisture limits can be observed:
1) A lower limit where flowability will deteriorate resulting in increasing product strength, a reducing discharge rate, an increased tendency to arch, rat-hole and hang-up formation.
2) An upper limit where the bulk solid is saturated (all voids filled) and flowability improves again.
Testing the product strength at different moisture levels is considered an important task in bulk solid's characterization.

4.4 Feeding System for Bulk Solids Handling

Of the various modes at transporting bulk solids, belt conveying is clearly one of the most effective and reliable and well suited to handling bulk solids over a wide range of tonnage rates. The success of belt conveyors depends on a number of factors, not the least of which is the initial feeding of the bulk solid onto the belt and to the efficient transfer of solids from one belt to another at conveyor transfer stations. With the future trend towards higher belt speeds and narrower belts in order to achieve higher economic efficiency, much attention will need to be given to the design of belt feeding systems which will guarantee high feeding rates with minimum of spillage and belt wear.

While the basic objectives of an ideal feeding arrangement for loading conveyor belts are fairly obvious, it is important that they be noted. Such objectives may be summarised as follows:

a) Free and uniform flow of material without segregation at a pre-determined flow rate in the same direction as the belt travel and preferably at the same speed.
b) Uniform deposition of material about the centre of the belt.
c) Avoidance of material spillage and dust problems.
d) Minimisation of abrasive wear and impact damage.

The feeding of bulk solids onto belt conveyors is normally controlled by a gravity flow hopper/feeder combination and, in the majority of cases; the solids are finally directed onto the belt through a gravity flow chute. The feed hopper may be a part of a surge bin (fig-4.26 a) or a part of a stockpile reclaims system (fig-4.26 b). Alternatively it may be a separate dump hopper for unloading trucks or rail wagons (fig-4.26 c) and (fig-4.26 d) respectively.

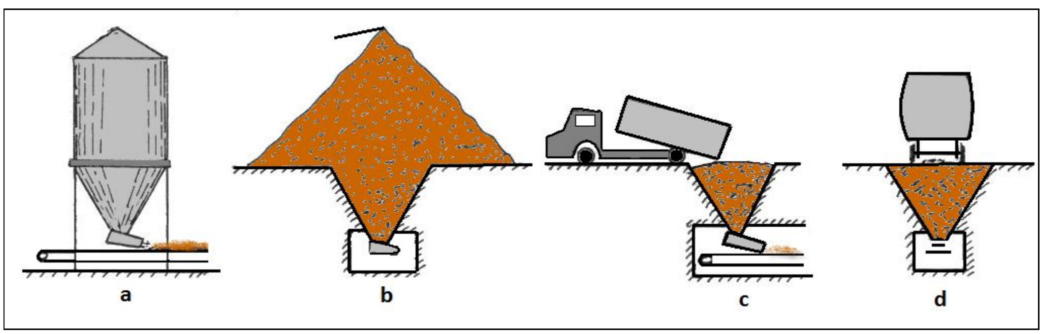

Figure-4.26: Hopper/ Feeder Combinations for Loading Conveyor Belts

Feed rates are controlled by the hopper and feeder as an integral unit while the feed chute in the flow directing and feed velocity controlling device. It is important that the interactive roles of these components as an integrated system be understood.

4.4.1 Types of Feeder for Bulk Solids Handling

Feeders for controlling the flow of bulk solids onto conveyor belts require certain criteria to be met:
1) Deliver the range of flow rates required.
2) Handle the range of particle or lump sizes and flow properties expected.

3) Deliver a stable flow rate for given equipment setting. Permit the flow rate to be varied easily over the required range without affecting the performance of the bin or hopper from which it is feeding.
4) Feed material onto the belt in the correct direction at the correct speed with the correct loading characteristic and under conditions which will produce minimum impact, wear and product degradation. Often a feed chute is used in conjunction with the feeder to achieve these objectives.
5) Fit into the available space.

It is important that the flow pattern be such that the whole outlet of the feed hopper is fully active. This is of fundamental importance in the case of mass-flow hoppers. When feeding along slotted outlets in wedge- shaped hoppers the maintenance of a fully active outlet requires the capacity of the feeder to increase in the direction of feed. To achieve this condition special attention needs to be given to the design of the outlet as vertical skirts and control gates can often negate the effect of a tapered outlet. Gates should only be used as flow trimming devices and not as flow rate controllers. Flow rate control must be achieved by varying the speed of the feeder. Various types of feeders to feed bulk solids onto belt conveyors are used and modified in cement industry.

4.4.1.1 Vibratory Feeders

Vibratory feeders are used extensively in controlling the discharge of bulk solids from bins and stockpiles and directing these materials onto conveyor belts. They are especially suitable for a broad range of bulk solids, being able to accommodate a range of particle sizes and being particularly suitable for abrasive materials. However they are generally not suited to fine powders under 150 to 200 mesh where flooding can be a problem. Also 'sticky' cohesive materials may lead to build-up on the pan leading to a reduction in flow rate. Bulk solids are conveyed along the pan of the feeder as a result of the vibrating motion imparted to the particles (fig-4.27). The pan of the feeder is driven in an approximate sinusoidal fashion at some angle theta to the trough. The conveying velocity and throughput depend on the feeder drive frequency, amplitude or stroke, drive angle and trough inclination, coefficient of friction between the bulk solid and the pan as well as the bulk solid parameters such as bulk density, particle density and general flow properties.

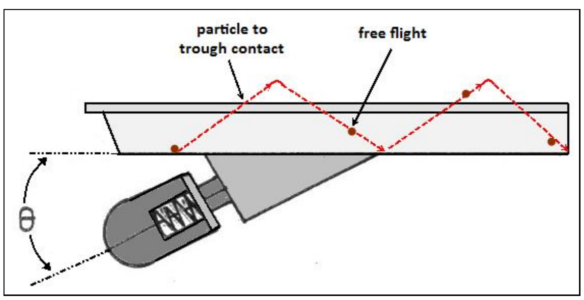

Figure-4.27: Movement of Particles by Vibration

In general vibrating feeders are classified as 'brute force' or 'tuned' depending on the manner in which the driving force imparts motion to the pan.
As the name implies 'brute force' type feeders involve the application of the driving force directly to the pan (fig-4.28). These feeders have the following characteristics:
a) Lower initial cost but higher operating costs.
b) Greater forces to be accommodated in the design.
c) Impact loads on the pan are transmitted to bearings on which out-of-balance weights rotate.
d) Delivery rates are dependent on the feeder load due to bulk solids.
e) Generally confined to applications requiring only one feed rate.

On the other hand 'tuned' vibrating feeders are more sophisticated in their operation in as much as the driving force is transmitted to the pan via connecting springs (fig-4.29). In this way they act essentially as a two mass vibrating system and employ the principle of force magnification to impart motion to the pan. The primary driving force is provided by either an electromagnet or by a rotating out-of-balance mass system.

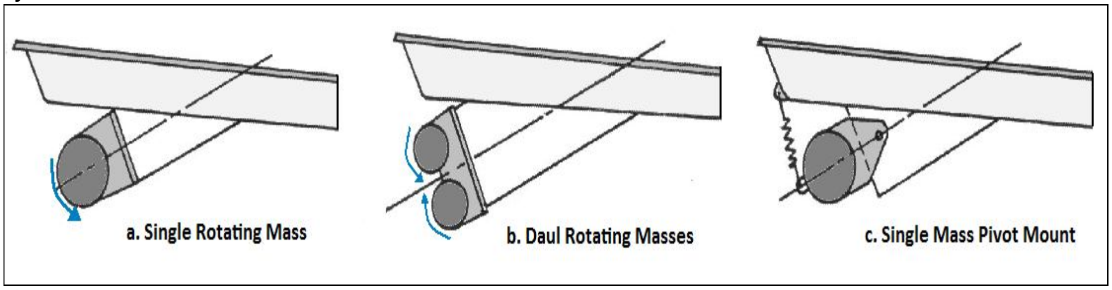

Figure-4.28: Brute Force Type Vibratory Feeders

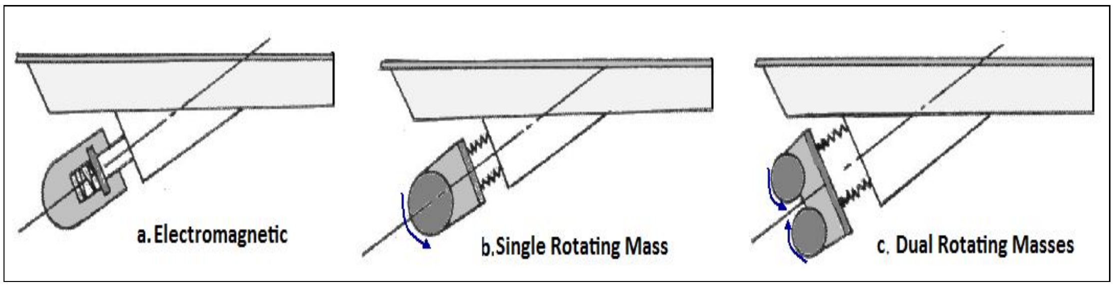

Figure-4.29: Tuned Type Vibratory Feeders

There are several aspects to note when designing feed hoppers for use with vibrating feeders. The effectiveness of the feeder (as with all feeders) depends largely on the hopper which must be capable of delivering material to the feeder in an uninterrupted way.

For a symmetrical hopper there is a tendency for the feeder to draw material preferentially from the front of the hopper. Uniform draw can be achieved by making the hopper outlet asymmetrical with the back wall at the correct hopper half angle (α) and the front wall at an angle of α + (5° to 8°).

Alternatively a symmetrical hopper may be made to feed approximately uniformly by using a rougher lining material on the front face. Other recommendations (fig-4.30) include:

a) Dimension E to be at least 150 cm.

b) B to be large enough to prevent arching or ratholing.

c) Gate height H to be chosen primarily to achieve an acceptable flow pattern rather than to vary the flow rate.

d) For high capacity feeders skirt plates extending to the outlet of the trough may be required.

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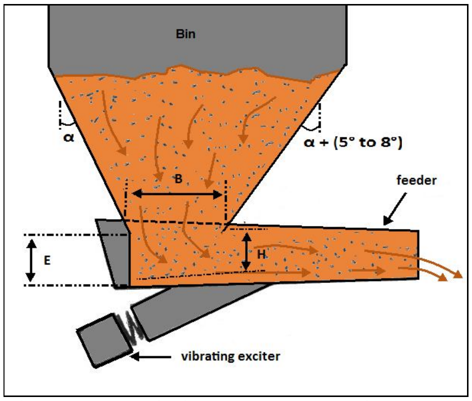

Figure-4.30: Typical Arrangement for Vibratory Feeder

4.4.1.2 Belt Feeders

Belt feeders are used to provide a controlled volumetric flow of bulk solids from storage bins and bunkers. They generally consist of a flat belt supported by closely spaced idlers and driven by end pulleys (fig-4.31). In some cases, hoppers feed directly onto troughed conveyors as in the case of dump hoppers used in conjunction with belt conveyors.

Some particular features of belt feeders include:

a) Suitable for withdrawal of material along slotted hopper outlets when correctly designed.
b) Can sustain high impact loads from large particles.
c) Flat belt surfaces can be cleaned quite readily allowing the feeding of cohesive materials.
d) Suitable for abrasive bulk solids.
e) Capable of providing a low initial cost feeder which is dependable on operation and amenable to automatic control.

With respect to the first point, the hopper and feeder geometry for long slots are critical if uniform draw is to be obtained. While normally feeders are installed horizontally, on some occasions a feeder may be designed to operate at a low inclination angle (β) up to 5° (fig-4.31).In particular, as stated previously, the gate opening H should be used to train the flow pattern and not to control the flow rate. As has been demonstrated by experiment, incorrect setting of the gate will cause non uniform draw with funnel-flow occurring either down the back wall or down the front wall. In one series of experiments using a free flowing granular type material, merely increasing the gate setting H causes the flow to move progressively towards the front. The final gate setting needs careful adjustment if uniform draw is to be achieved. Thus in belt feeders flow rate variations must be achieved by varying the belt speed. This requirement places some limitations on belt feeders when very low flow rates are required, especially if the bulk solid is at all cohesive or contains large lumps.

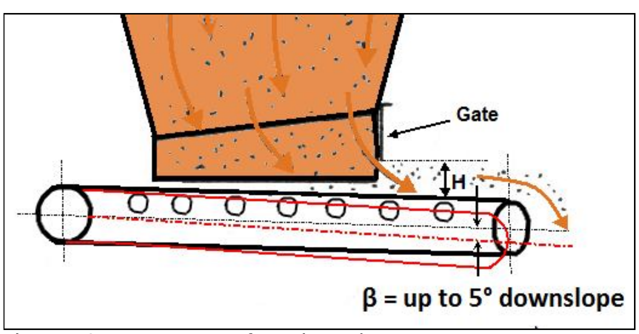

Figure-4.31: Arrangement for Belt Feeder

Particular care is needed with the design of the hopper/feeder arrangement when handling fine powders in order to ensure that problems of flooding are avoided. If the bulk material tends to stick to the belt, spillage may be a problem with belt feeders. Therefore if sufficient headroom is available, it is desirable to mount the feeder above the belt conveyor (fig-4.32) onto which it is feeding material in order that any material falling from the return side of the belt will automatically fall onto the conveyor belt.

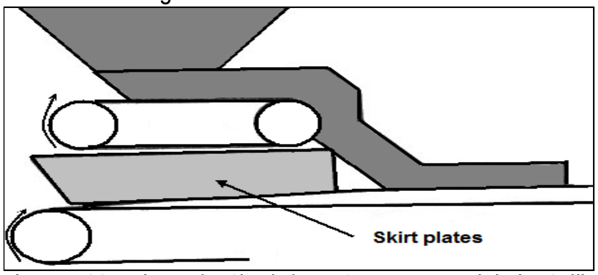

Figure-4.32: Belt Feeder Sited above Conveyor to Minimise Spillage

Belt feeders can also have applications where a short speed-up belt is used to accelerate the material at the loading point of a high speed conveyor (fig-4.33). The accelerating conveyor avoids wear that would otherwise occur to the cover of the long conveyor.

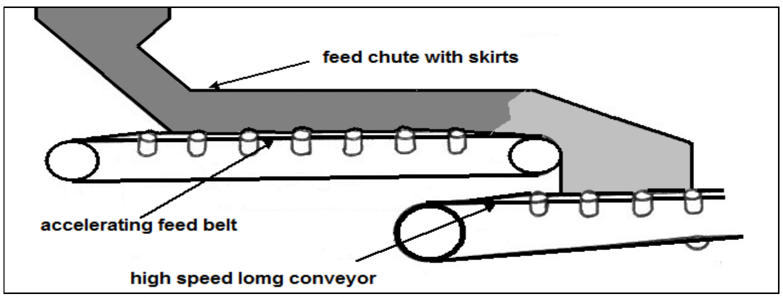

Figure-4.33: Belt Feeder as Acceleration Conveyor

4.4.1.3 Apron Feeders

Apron feeders are a version of belt feeders and are useful for feeding large tonnages of bulk solids being particularly relevant to heavy abrasive ore type bulk solids and materials requiring feeding at elevated temperatures. They are also able to sustain extreme impact loading. The remarks concerning the need for uniform draw and gate settings applicable to belt feeders are also applicable to apron feeders. The figure (fig-4.34 a) shows an apron feeder with parallel outlet which is inducing funnel-flow down the rear wall of the hopper. Apart from the obvious flow problems, the funnel-flow pattern developed will accelerate the wear down the rear wall. In tapered outlet (fig-4.34b), when correctly designed will induce uniform draw, minimising segregation and minimising hopper wall wear.

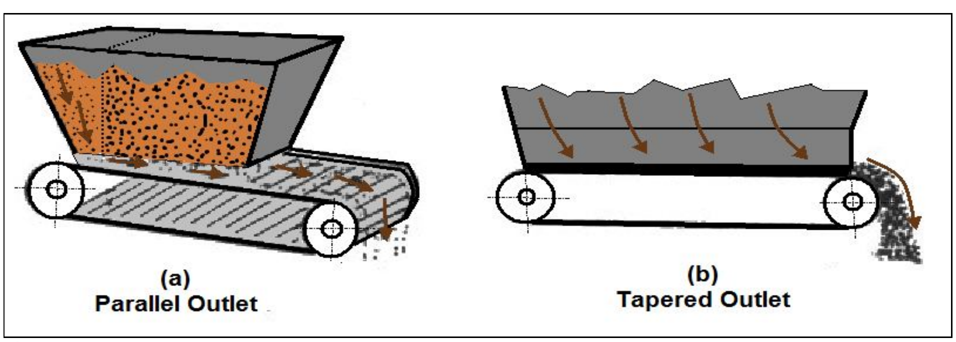

Figure-4.34: Apron Feeders

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4.4.1.4 Plough Feeders

Rotary plough feeders are generally used in long reclaim tunnels under stockpiles where they travel along the tunnel (fig-4.35) or fixed under stockpiles and large storage bins (fig-4.36). In the case of the stockpile slot reclaim system (fig-4.35), it is necessary for the diagonal dimension of the slot to be at least equal to the critical rathole diameter D_f of the bulk solid in order to prevent ratholes from forming under the high storage pressures. In this way the gravity reclaim efficiency is maximized. The tie beams between slots should be steeply capped. Furthermore the slot width B_f must be large enough to prevent arching.

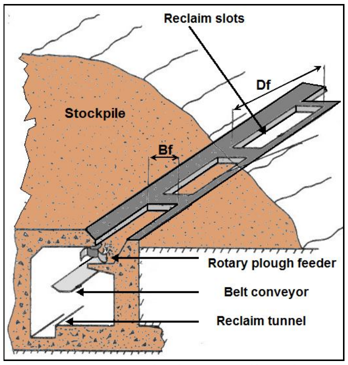

Figure-4.35: Typical Stockpile with Paddle Feeder Reclaim System

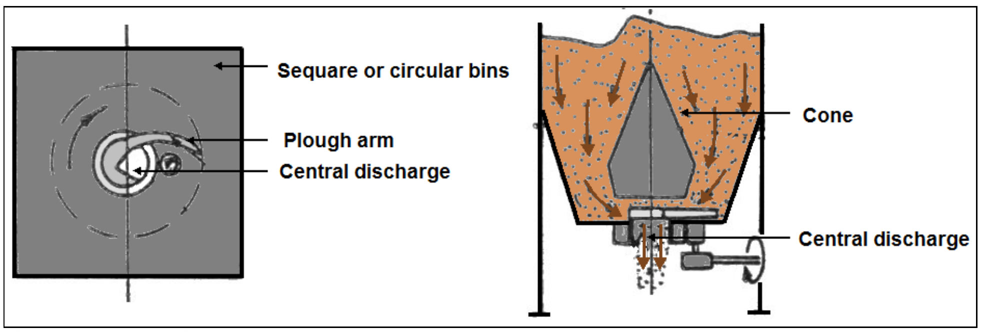

Figure-4.36: Fixed Plough Feeder

The basic concept of the travelling plough feeder is to allow bulk solids to flow by gravity onto a stationary shelf and then remove the solids from the shelf either with a linear drag plough or a travelling rotary plough. It is important that high penetration of the plough is achieved and that there is a small vertical section behind the plough to prevent material build-up on the sloping back wall (fig-4.37).

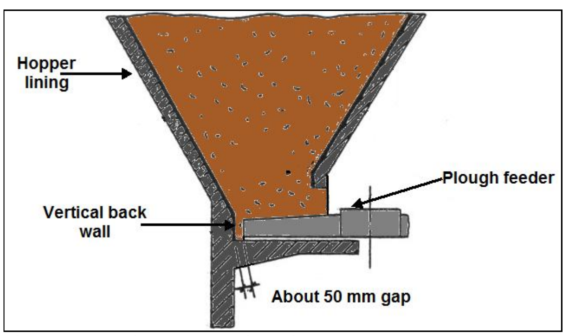

Figure-4.37: High Penetration Plough Feeder

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4.4.1.5 Rotary Table Feeders

The rotary table feeder can be considered as an inverse of the plough feeder. It consists of a power driven circular plate rotating directly below the bin opening, combined with an adjustable feed collar which determines the volume of bulk material to be delivered (fig-4.38). The aim is to permit equal quantities of bulk material to flow from the complete bin outlet and spread out evenly over the table as it revolves. The material is then ploughed off in a steady stream into a discharge chute.

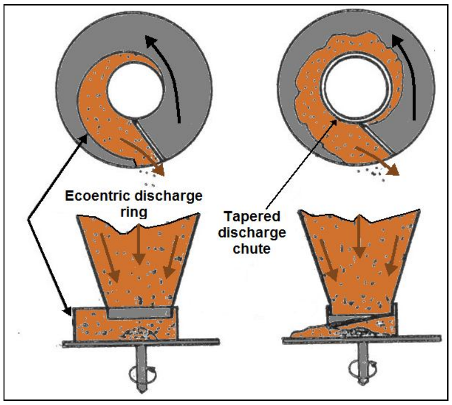

Figure-4.38: Rotary Table Feeder

This feeder is suitable for handling cohesive materials which require large hopper outlets, at flow rates between 5 and 125 tonnes per hour. Feed rates to some extent are dependent on the degree to which the material will spread out over the table. This is influenced by the angle of repose of the material which varies with moisture content, size distribution and consolidation. These variations prevent high feed accuracy from being obtained. Rotary table feeders are suitable for bin outlets up to 2.5 m diameter; the table diameter is usually 50 to 60% larger than the hopper outlet diameter. With some materials a significant dead region can build up at the centre of the table. This can sometimes be kept from becoming excessive by incorporating a scraping bar across the hopper outlet. It is important to ensure that the bulk material does not skid on the surface of the plate, severely curtailing or preventing removal of the bulk material.

4.4.1.6 Screw Feeders & Dischargers

Screw feeders are widely used for bulk solids of low or zero cohesion such as fine and granular materials which have to be dispensed under controlled conditions at low flow rates. However (as with belt feeders) design difficulties arise when the requirement is to feed along a slotted hopper outlet (fig-4.39). An equal pitch, constant diameter screw has a tendency to draw material from the back of the hopper as in (fig-4.39 a). To counteract this, several arrangements are advocated for providing an increasing screw capacity in the direction of feed as in (fig-4.39 b to f). The arrangements shown are: Stepped pitch, Variable pitch, Variable pitch and diameter, & Variable shaft diameter.

Pitch variation is generally limited to a range between 0.5 diameters minimum to 1.5 diameters maximum. This limits the length to diameter ratio for a screw feeder to about six, making them unsuitable for long slots.

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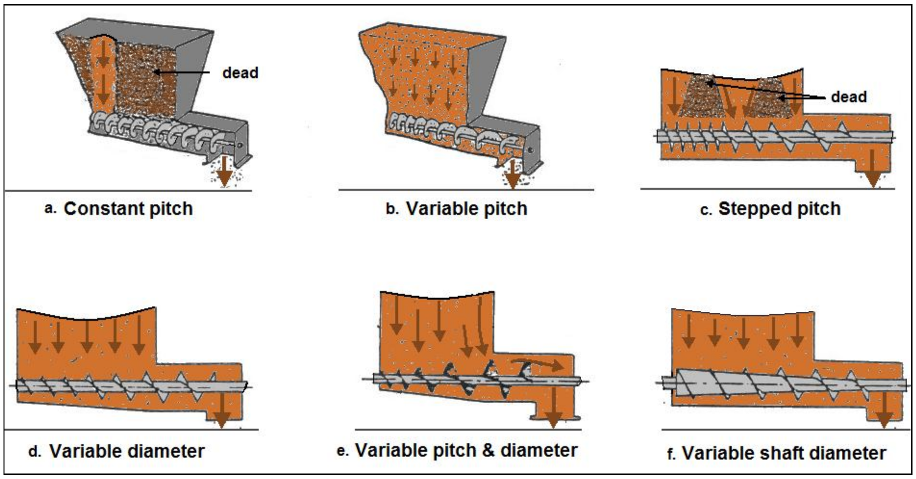

Figure-4.39: Screw Feeding Along Slot

The section of the screw leading from the hopper to the feeder outlet is fundamental in determining the quantity of material discharged per revolution of the screw. At the point where the screw leaves the hopper, it is essential for control purposes to cover the screw, normally by a 'choke' section having the same radial clearance as the trough. This choke section should extend for at least one pitch to prevent material cascading over the flights.

As a screw feeder relies on friction to transport material it has a very low efficiency in terms of the energy requirements. Furthermore, the volumetric efficiency is impaired somewhat due to the rotary motion imparted to the bulk material during the feeding operation.

Since screw feeders are generally fully enclosed, relatively good dust control is achieved. However due to the high frictional losses abrasive type bulk solids can effectively reduce the life of the feeder due to abrasive wear. Fine powders that tend to flood are difficult to control in a screw feeder in flooding situations.

Screw Discharges: screw dischargers are variations of the normal screw feeder. Two of the more commonly used versions are shown in the figure (fig-4.40). (Fig-4.40 a) shows a single screw which is forced to circle slowly around the bottom of a flat bottom storage silo. The screw rotates at the same time and slices the bulk material, transferring it to a central discharge chute. In (fig-4.40 b), the whole floor of the silo rotates about a fixed axis. The bulk material is forced against the rotating screw as the silo bottom rotates.

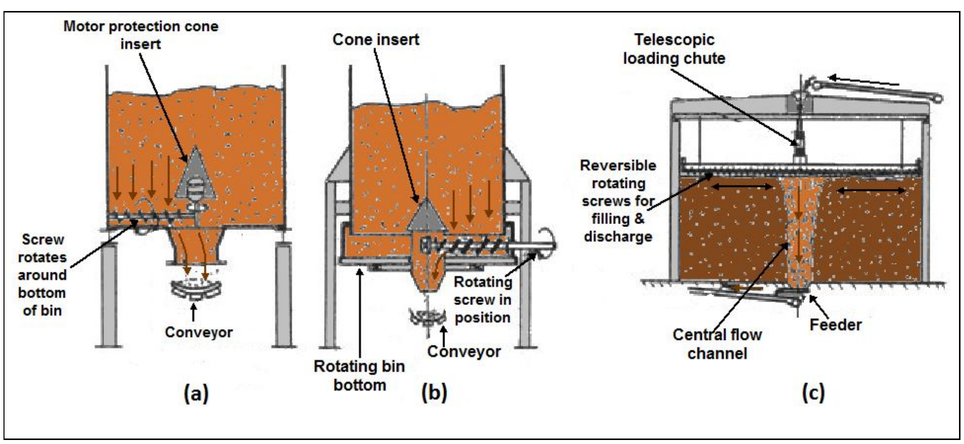

Figure-4.40: Various Screw Discharge Arrangements

Screw discharges have been used successfully with some wet (sticky) bulk solids which have not been handled effectively using other means. In addition to providing the necessary flow promotion, these

devices also control the feed rate. Problems could arise when devices of this type suffer breakdown need careful investigation when considering a screw discharge device for use in a particular application.
An alternative application of screw discharges which is shown schematically in (fig-4.40 c) originated in the Netherlands and (as indicated) the screws sweep around the top surface drawing material to the central discharge channel. The screws are also used to distribute the bulk material during filling. This system was originally developed as an inexpensive storage facility, for potato starch but it is now being used for other bulk materials, notably coal. It provides a very large capacity, environmentally clean storage facility. Its principal disadvantage is that it operates on a first-in last-out sequence and hence is not recommended for materials that degrade with time.

4.4.1.7 Rotary Feeders

Rotary feeders (also known as drum, vane, star and valve feeders) are generally used for the volumetric feeding of fine bulk solids which have reasonably good flowability.
A rotary drum feeder (fig-4.41 a) might be considered an extremely short belt feeder. The drum prevents the bulk material from flowing out but discharges it by rotation. This feeder is only suitable for materials with good flowability which are not prone to aeration. Similar considerations apply to the rotary vane feeder (fig-4.41 b) which might be considered as an extremely short apron feeder; (fig-4.41 c) shows some modifications to the vane. The rotary valve feeder (fig-4.42 a) is completely enclosed and aims at preventing powders or fine grained materials from flooding. The star feeder (fig-4.42 b) provides a means for obtaining uniform withdrawal along a slot opening. These feeders are not suitable for abrasive bulk materials as clearances cannot be maintained and the feeders tend to lose control especially when handling aerated powders. Cohesive powders will tend to clog the rotor pockets and reduce feeder capacity.

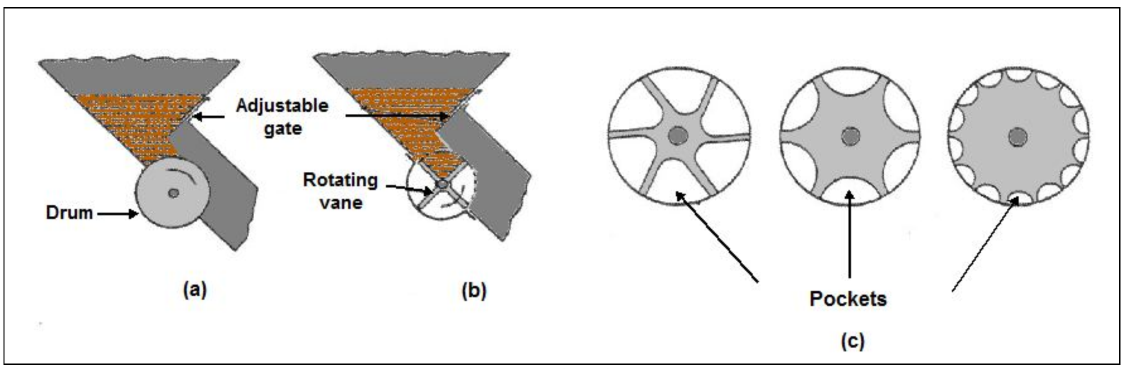

Figure-4.41: Rotary Drum & Vane Feeders with Various Rotating Elements

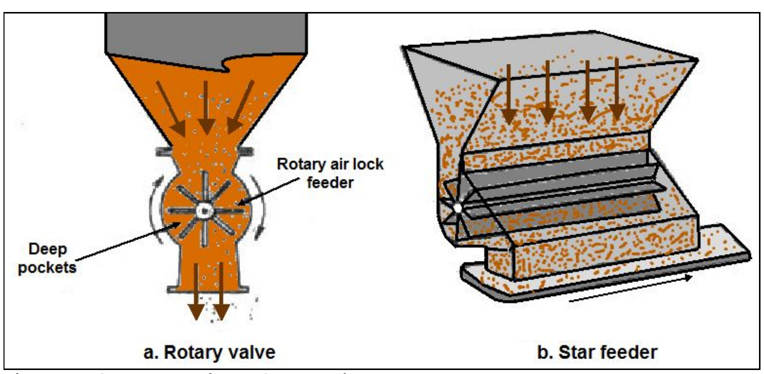

Figure-4.42: Rotary Valve & Star Feeders

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The selection of a feeder for a particular situation is not always simple, especially if more than one satisfactory solution appears possible. The type and size of feeder for a given application is primarily dictated by the characteristics of the bulk material to be handled and the required capacity.

From a design point of view it is important to be able to determine with some accuracy the loads acting on feeders in hopper/feeder combinations and the corresponding power requirements. Yet the state-of-the-art has (in the past) been such that the loads and power requirements could not be estimated with any degree of precision. For instance it has been observed that the majority of formulae published are empirical in nature and derived to predict loads and corresponding power requirements for feeders used in conjunction with funnel-flow bins. These formulae are inadequate when applied to mass-flow bins since (in such cases) the loads and power requirements are often greatly underestimated. This is largely due to the fact that in mass-flow bins the full area of the hopper outlet is presented to the feeder.
The loads acting on feeders can vary considerably. There are many reasons for this, some more obvious than others. It was indicated that the shape of the hopper outlet will influence the load on a feeder (fig-4.43). In (fig-4.43 a), the full load (not equal to the hydrostatic head) acts on the feeder. In (fig-4.43 b) the load is partly reduced by changing the shape of the hopper. In (fig-4.43 c), the load is completely removed from the feeder and only acts on the hopper wall. Although the advantages of (fig-4.43 b & c) appear obvious, the solution may not be as simple as that depicted. It is clear that the flow pattern developed in the feeding operation must be such that uniform, non-segregated flow is achieved at all times.

The loads acting on feeders and corresponding power requirements are influenced by several factors. These include the following:
a) Hopper flow pattern, whether mass-flow or funnel-flow.
b) Flow properties of the bulk solid.
c) The chosen hopper shape which in the case of mass-flow includes axi-symmetric or conical, plane-flow or transition (combination of conical and plane-flow).
d) The actual hopper geometry.
e) The wall friction characteristics between the bulk solid and hopper walls and skirt plates.
f) The type of feeder and its geometrical proportions.
g) The initial filling conditions when the bin is filled from the empty condition and the flow condition when discharge has occurred.

The most efficient and reliable feeding performance is achieved by using a mass-flow hopper/feeder combination. For a given bulk solid and hopper/ feeder geometry the load acting on a feeder varies considerably between the initial load (when the bin is first filled) and the load either during flow or after flow has stopped. It has indicated that the initial load can be 2 to 4 times the flow load. However, the researchers have shown that the variation is much greater than this with the initial loads of the order of 4 to 8 times that of the flow load. Theoretical predictions show that circumstances can arise whereby the initial/flow load variations can be much higher than those indicated.

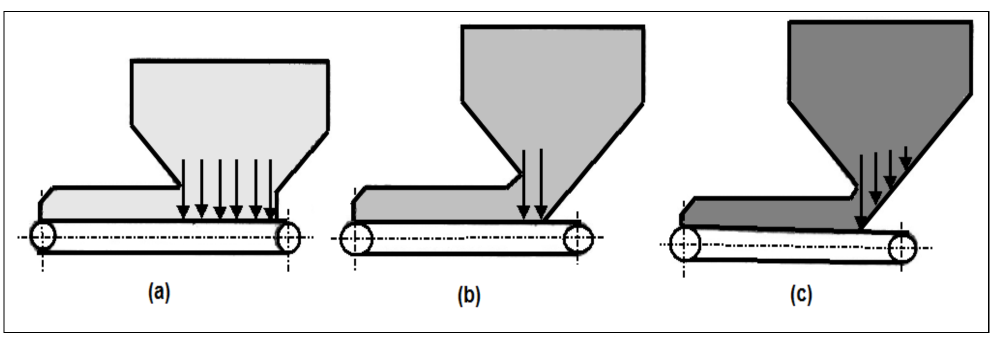

Figure-4.43: Varying Load on Feeder by Varying Hopper Configuration

4.4.2 Feed Chutes

As outlined before, the role of feed-chutes is to direct bulk solids from bins and feeders onto conveyor belts in a manner which will minimise spillage and belt wear. Chute may also be designed in a manner which will ensure the component of the exit velocity tangential to the belt V_T (fig-4.44) is matched as closely as possible to the belt speed. While the normal component V_N of the exit velocity should be as small as possible to minimise impact damage to the belt, it is necessary to ensure continuity of feed with sufficient chute slope to maintain flow and prevent choking. The figure (fig-4.45) shows the velocity of bulk solids flow in different models of chute.

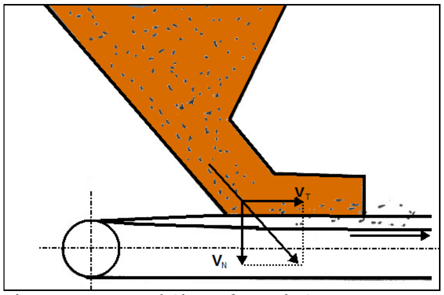

Figure-4.44: Feed Chute for Belt Conveyor

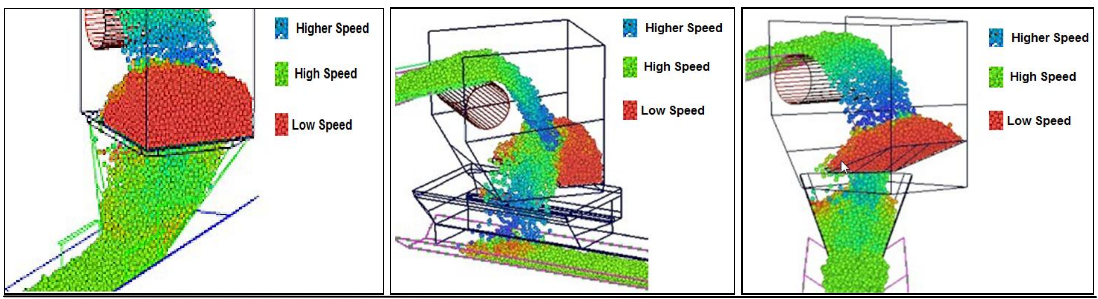

Figure-4.45: Velocity of Bulk Solids in Different Models of Chute

4.4.2.1 Chute Friction & Slope Angles

There are many lining materials available and these need to be selected on the basis of their frictional and wear resistance properties. It is also important to consider any corrosive influence of the bulk solid on the hopper wall. It has been found that certain coals (for example) will build up on mild steel surfaces even after a short contact time of a few hours. The type of behaviour found to occur in practice is illustrated in the figure (fig-4.46), moist coal from a screen has been found to adhere to vertical mild steel surfaces as indicated; particularly where the initial velocity of the coal in contact with the surface is low.

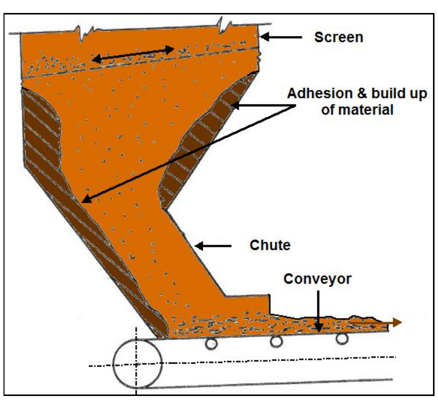

Figure-4.46: Build up of Cohesive Material on Chute Surfaces