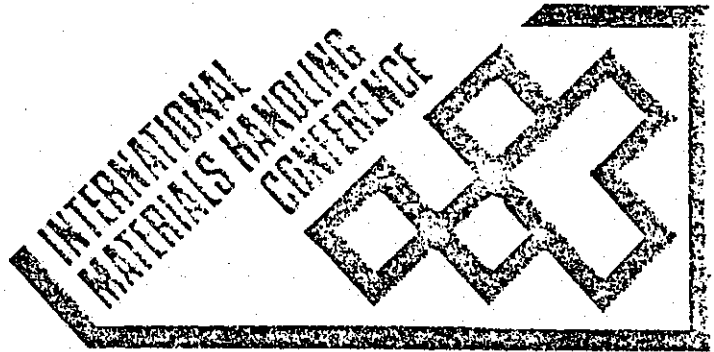


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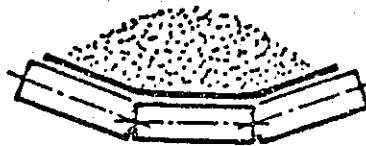


RATIONAL DESIGN OF CONVEYOR CHUTES

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BELT CONVEYORS - DESIGN, OPERATION AND OPTIMIZATION

RATIONAL DESIGN OF
CONVEYOR CHUTES

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RATIONAL DESIGN OF CONVEYOR CHUTES

1. SUMMARY

A review of Commissioning Reports has shown that detailers of conveyor chutes frequently lack understanding of basic theoretical and practical aspects of chute design.

This paper reviews fundamental principles of material flow properties, mass flow through chutes, spillage at transfer points, friction in long chutes, as well as problems of wear and maintenance access.

2. INTRODUCTION

Considerable time and money is spent fixing up conveyor chutes on site.

Engineering expertise must be a blend of basic knowledge and practical experience. Unfortunately the chute detailer is frequently limited in both the theoretical and practical aspects of chute design. Often the draughtsman is left to do his best without any engineering support.

In view of the importance of correct chute design the Bionic Research Institute has initiated an in-depth study of the subject.

3. Review of Commissioning Reports

A review of Commissioning Reports has shown that detailers of platework do not always pay sufficient attention to detail. Typical of the problems encountered are the following:

- A chute was designed for a 600 mm conveyor and not for the 750 mm belt installed. The detailer had worked on old drawings.

- Curbing around a lowhead screen had to be chipped to accommodate the feed chute lip.
- The steelwork at the head of the conveyor gantry was found to be directly in the FLIGHT PATH of the material coming off the conveyor. No head chute had been allowed for in that design.
- The underflow chute was too short so that gravels falling through at the end of the screen MISSED THE CHUTE and fell onto the floor.
- The discharge chute was UNLINED despite the fact that the chute was handling up to 600 tph of gravel.
- The chutes delivering from the grizzlies to the primary screen were lined with polyurethane liners to prevent excessive wear. These liners were not adequately fitted and kept dropping out.
- A chute flap gate was provided but HAD NO HANDLES for operation.
- The grooves, in which wheel and ratchet sliding doors were supposed to operate were PERMANENTLY SEALED with rock and compacted fines - making it impossible to seal off the primary feeders.
- The boulder doors have not been FREE to move on the shaft. Bushes were fitted with so little clearance that grease could not be pumped into them.

4. Feeder Chutes Block Up

The review also indicated that chute designers often do not have a clear understanding of the technical aspects of chute design.

"The head chute front plate wears quickly", complained one commissioning engineer. "The trajectory is too high and the front plate is restricting the natural flow of material".

"At the head end of the fines conveyor the 'dead box' area appears to be too large", wrote another, resulting in frequent choking of the chute. The free distance between head pulley and dead material is too small, possibly due to the angle of repose of the material being higher than anticipated.

"The chute at the head of the conveyor was too narrow for the size of the material, and the capacity the conveyor was expected to deliver".

"The undersize chute from the primary scalper has blocked when treating damp and clay material. There is a tendency for larger rocks to 'bridge' in the Y-chute above the secondary scalpers. Further blockages occur in the same chutes because the distance between the chute bottom and the screen deck is too small".

Loss of control of the flowing material is a problem experienced at many plants.

"Vibrating feeders gave no EFFECTIVE CONTROL over the flow of material from the crusher bin to the conveyor delivering it to the primary stockpile", writes one commissioning engineer.

"In particular, when the proportion of sand in the feed was high, the material flowed over the feeder at the same rate at which it was DUMPED into the crusher, thus overloading the belt and causing considerable spillage".

Another engineer described the problem as follows:

"The secondary crusher feed is comprised of:

1. coarse rock
2. fine rock
3. any proportionate mix of rock and sand
4. damp clay

"The feeders can be set to feed coarse rock and they can be set to feed sand, but no single common setting can cater for any proportionate mix of rock and sand. A setting for sand completely retards the flow of rock, or a mix of sand and rock. A setting for rock gives no control over the flow of sand. Damp clay packs the feeder pan and creates a condition where no feed at all can be obtained".

(Isn't it about time we designed A NEW FEEDER which would cope with just this type of problem?)

The chute designer must know, and understand, the characteristics of the material the system is handling - and how these characteristics change through the process plant.

5. Flow properties vary

The "bulk solids" handled by conveyors can range from coarse broken solids, consisting of large lumps, down to powders or ultra-fine particles of submicron size.

There are obvious differences between coarse, fine, and powdered materials. Only fine materials - alone or in a mixture with coarser ones - show cohesive properties. They build cohesive arches. Only coarse materials can cause mechanical interlocking.

Bulk solids are least free-flowing when their moisture content is in the range of 70 to 90% of saturation. In storage a saturated bulk solid usually will drain until it reaches the range of minimum flowability. The moisture content of fine coal, for example, has an important effect on its handling characteristic. This is particularly pronounced if the minus 12 mm particle size is more than 10%. Time in storage is also a factor. Many bulk solids are free-flowing if they are kept in motion, but cake severely when stored at rest for a few hours.

The percentage of a sample passing the 0,075 mm mesh has a powerful effect on the cohesion of the sample. This is the silt and clay size fraction. Larger material, free of fines less than 3 mm size, are generally free flowing.

Changes in particle size distribution, and hence material flow properties, of material passing through a process plant can be studied by plotting the results of screen size to percentage passing on log - log paper. Such a graph will readily show up the effects of crushing and screening on both oversize and undersize materials.

General tables of flow properties are a poor guide. Each material should be TESTED for flow, using conditions simulating the conditions under which the material will be handled in the plant.

6. Don't guess - TEST flow properties

For design of loading chutes CEMA makes the following recommendation.

"Obviously, the loading chute must be inclined in order to give the material flow a desirable forward velocity. If the material is fine and contains some moisture, the chute must be made steep enough so that the material will slide rapidly. However, if the material is lumpy, the steepness of the chute is limited to that angle at which the material will slide satisfactorily, but not bounce or tumble".

Let's be honest! How often does the chute designer know the angle at which the material will slide but not bounce?

At the intake end of the process the material properties will vary considerably. But within what limits? Don't guess - TEST! How often does the chute designer have any test data at all with which to work? In far too many cases chute design is a hit-and-miss procedure.

What are the consequences on site?

What do the commissioning engineers say?

"Blockages occurred in the minus 200 plus 50 scalper undersize chute. Site modifications included increasing the angle at the chute base".

"The primary screening head chute chokes badly. The Mine has introduced rail liners as curtains - i.e. only the top of the liners are supported and the lower ends are free - midway after the two-way split. A considerable amount of water is introduced in the main chute as well as sprays being located behind the rail curtain".

"The transfer chute under the jaw crusher was choking badly".

"The primary screening head chute chokes badly".

"Chute blockages were experienced in the deadboxes under the primary crusher, secondary crusher, and conveyor head chutes. The bottoms of these dead boxes were lowered by 200 mm and to date no further blockages have occurred".

"Blockages occurred at numerous conveyor transfer chutes. Alterations included cutting away chute sides and providing chute covers. A feed chute was widened from 100 mm to 200 mm to prevent blockages".

It is clear from such report that, in far too many cases, chute design does not receive the serious design attention it deserves.

How often does the chute designer have a tangible understanding of the flow properties of the material being handled. How often does he mentally follow the flow through the chute, watching as it changes shape, speed, direction and flow stream thickness? How often does he try to estimate the limits of turbulence?

7. Mass flow through a chute

How can we assess the way bulk material will flow through a chute?

First we can assume that the mass flow rate is constant throughout the flow. The equation for continuity of flow is:

$$Q = w A V = \text{constant} \quad (1)$$

where w is the bulk density kg/m^3

A is the cross-sectional area m^2

V is the velocity m/s

and Q is the mass flow rate kg/s

Although some variation in bulk density would no doubt occur along the chute in most cases the variation is small. Therefore we can assume that the volume flow rate is constant.

$$A V = \text{constant} \quad (2)$$

At places of impact the bulk solids will rebound, effectively reducing the bulk density at that point. The turbulent energy is soon dissipated and the bulk density returns to its previous value.

(S.B. Savage reported on the phenomena of surge waves and granular jumps - analogous to hydraulic jumps - which form when obstructions are placed at the downstream end of a chute).

8. Is the chute an Orifice or a Weir?

Does the chute form an orifice or a flow weir? Where in the chute does this occur?

Look at a discharge chute under a bin or hopper. If the chute is large in relation to the aperture the discharge rate is governed only by the aperture and is not influenced by the chute. However, if the chute guides and shapes the material flow parts of the chute can form a flow restriction, or cause a granular jump, within the chute.

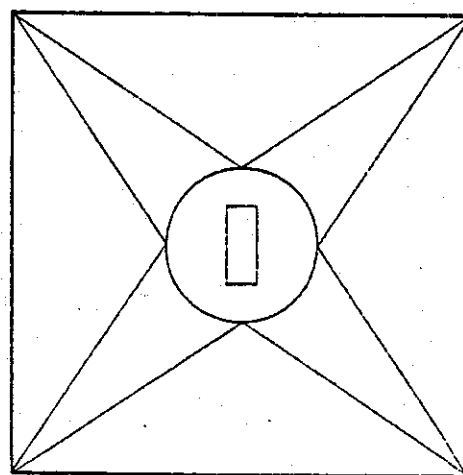
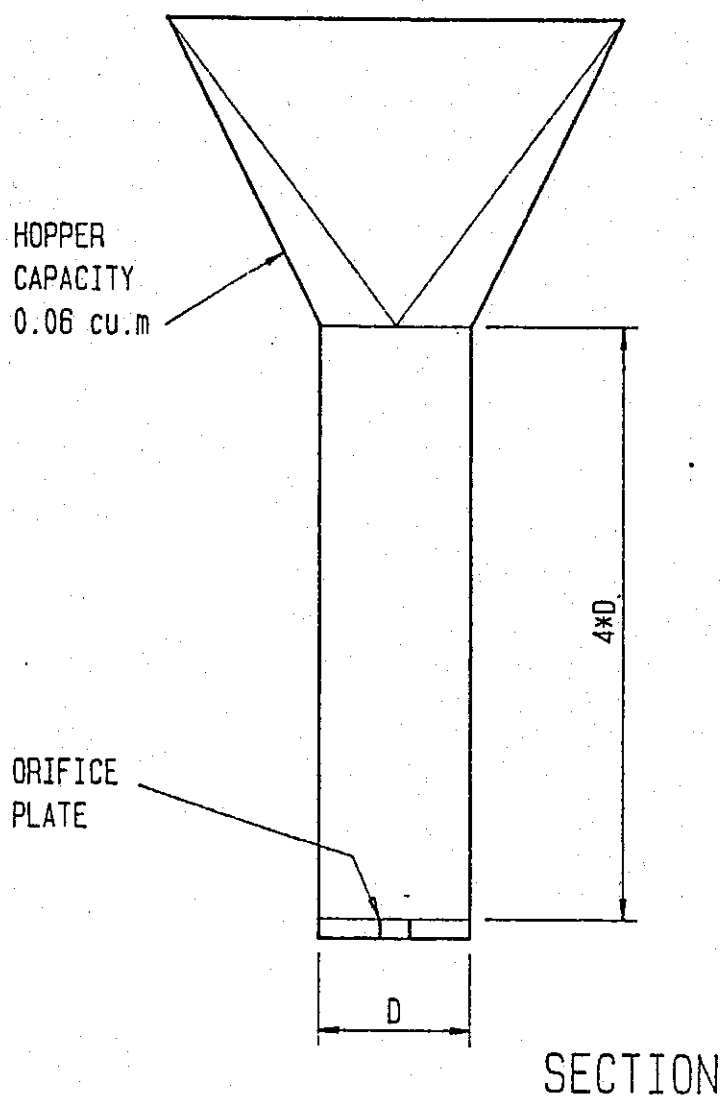
A study of chutes must therefore start with a study of the flow of material through an orifice.

9. Flow through an Orifice

The flow of bulk material through an orifice can easily be studied by the use of a flow funnel as shown in Fig. 1.

A change in the diameter of the body of the hopper produces no noticeable effect on the flow rate.

Provided the material level does not fall below a head of four times the funnel diameter, a change in material head also produces no change in flow rate.



PLAN OF FLOW FUNNEL

Fig 1. DETAILS OF FLOW FUNNEL

The minimum width of a loading chute should be at least 2,5 to 3 times the largest diameter of uniformly sized lumps, when these represent a considerable percentage of the material flow. These proportions are essential to the proper loading of the belt and to prevent interlocking and jamming of lumps in the chute.

But what effect do these narrow rectangular openings have on material flow? The effect of particle size on material flow increases with decreasing D/d ratios. Many field reports complain of chutes choking badly. Was the flow rate through the chute checked at the design stage? Did the chute designer have any test information on anticipated flow rates through long, narrow openings?

Did the chute designer have any test information? Grading analysis of the sample down to 0,075 mm? Flow funnel test data? Bulk density? Really?

Or was the chute design based on rough catalogue values, guesses, and hear-say? How much real engineering support do we give our chute designers?

Take for example the following CEMA recommendation for the design of loading chutes:

"While the loading of material onto a belt conveyor involves many considerations, of prime importance is the placing of the material centrally on the belt in such a manner that the material velocity in the direction of belt travel is, as nearly as possible, equal to the velocity of the belt itself".

Dimensional analysis suggests that the mass flow rate Q should be proportional to:

$$Q = C w D^{2,5} \quad (3)$$

where D is the orifice diameter m
and C is the orifice flow coefficient.

In many cases the flow will form a vena contracta at the orifice. This reduces the effective orifice width by 0,7 to 1,7 particle diameters. If d is the average screen size of the particles the actual throat diameter would therefore be reduced to $(D - kd)$, where k has a value between 0,7 to 1,7. Taking an average nominal value of 1,4, for the majority of materials with a bulk density about 0,7 tons/ m^3 , the estimated flow rate would be

$$Q = 1,83 w (D - 1,4d)^{2,5} \quad (4)$$

To obtain a more accurate value for the flow coefficient funnel tests should be made using specific material samples. The influence of particle shape expresses itself more or less in the values of w and d , and therefore need not be separately considered. Provided that the ratio of D/d exceeds 20, the effect of particle size on flow rate is negligible.

For a given area the circular orifice is the most efficient, the square orifice second, and the rectangular and triangular third.

In the case of a rectangular orifice flow is dependent upon orifice width as well as the ratio of length to width. The flow rate for orifices of various shapes can be estimated using equation 4, by substituting an equivalent diameter calculated from the orifice area.

This advice is hardly practical. Attempts to follow the advice will maximise belt wear. The wear rate of rubber rises rapidly at angles of impingement of less than 50° . The wear rate is very high at an impingement angle of about 22° .

Furthermore turning the flow through large angles in the chute may increase the speed component in the direction of belt travel, but it will dramatically reduce the flow rate through the chute.

To increase the material speed down the chute, the chute must be close to vertical - at 90° to a horizontal belt. But angles above 60° result in a rapid decrease in forward speed. Conversely, decreasing the chute angle has the effect of increasing the material speed component in the direction of belt travel. However, the material would flow very slowly through chutes with angles less than 30° to horizontal. And, to reduce belt wear the chute angle should not be less than 50° , particularly with abrasive materials.

10. The Chute as a flow weir

To understand more fully what happens in a chute, let us consider a curved discharge chute under a bin or hopper.

On entering the chute the material will fall freely, increasing in velocity as it accelerates. But, further down the chute, as a result of chute curvature and decreasing slope, the flow starts to slow down, as shown in Fig 2.

As the velocity decreases the stream thickness increases. Usually the build-up in stream thickness represents an unstable condition. Minor flow obstructions may cause a rapid deceleration of the stream with an increase in thickness near the end of the chute.

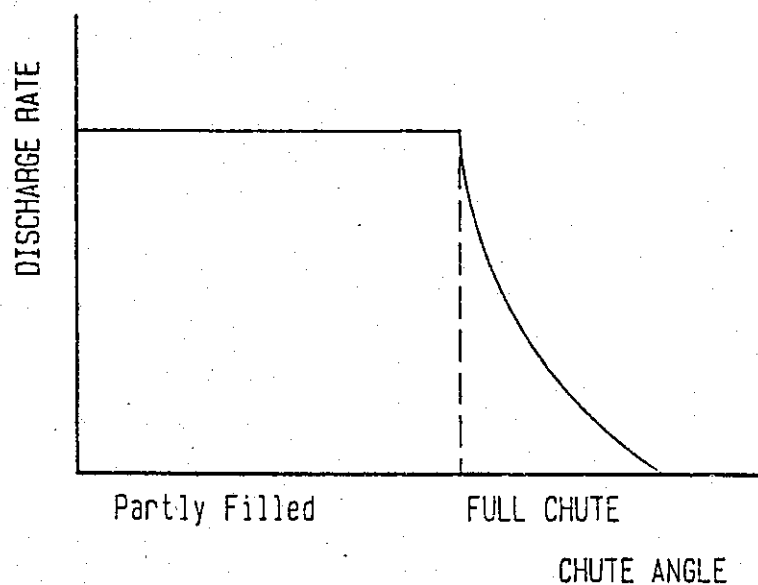
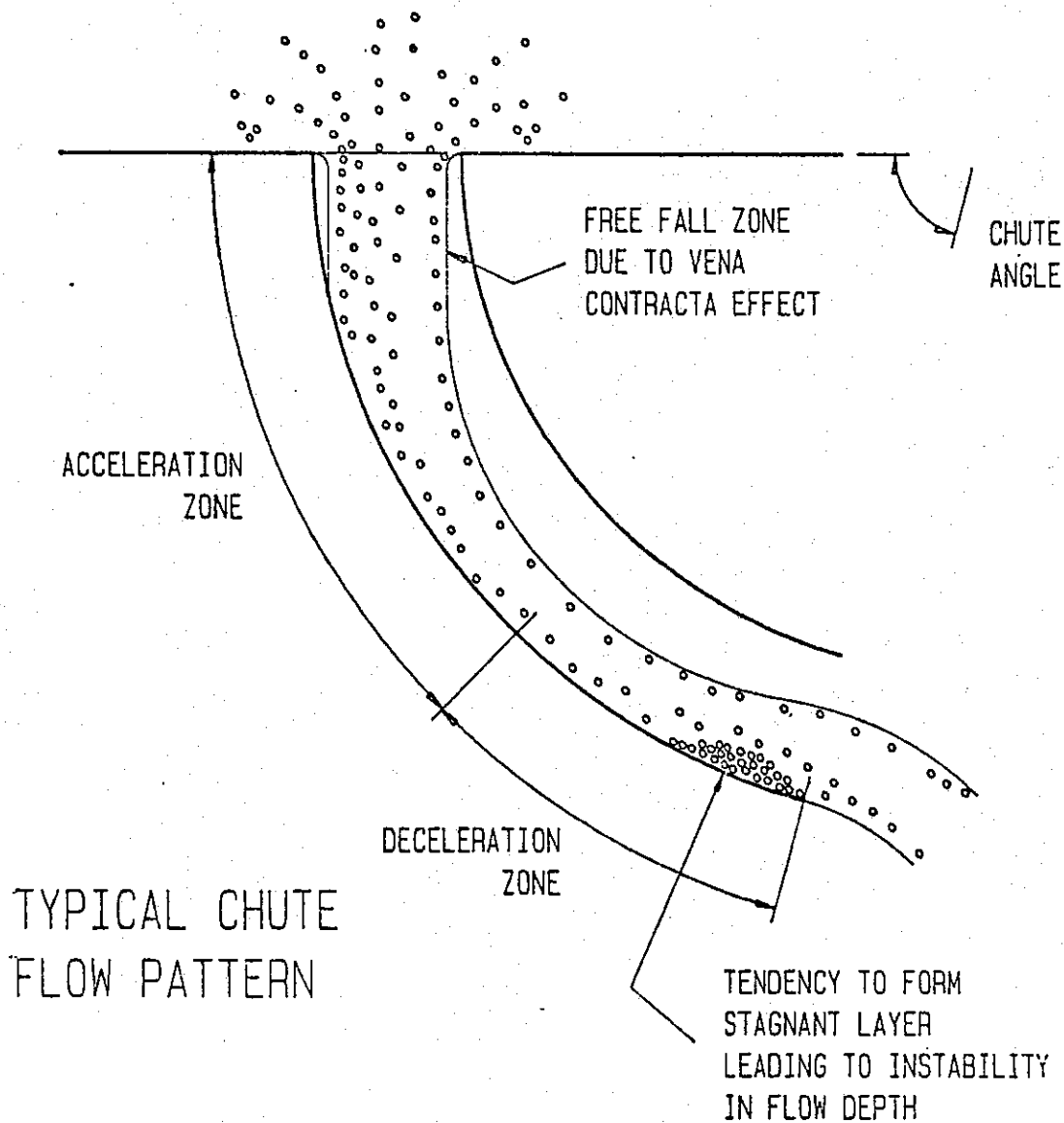


Fig 2. FLOW IN CURVED CHUTES

The stream thickness may build up to such an extent that contact is made with the top surface of the chute. The stream is then slowed down considerably. A surge wave of material flows upstream. The chute fills and the material flows en-masse at a uniform rate.

The chute now acts as an extension of the hopper and the chute geometry has a marked effect in reducing the flow rate. A flow obstruction, even though only momentary, may choke the flow in a closed duct, or cause spill-over in an open channel.

In chute design we are mainly interested in local effects. A study of such effects would considerably improve our success at chute design.

"The concept of feeding a conveyor through a long narrow opening is a good one, and prevents spillage and skirting damage", wrote one commissioning engineer". "The opening should, however, be wide enough to prevent choking".

The speed of the material as it leaves the loading chute is related to the velocity of the material entering the chute, the chute angle, the height of fall, the material density and the flowability of the material. At impact we can expect the bulk solids to rebound, causing turbulence. This turbulence is a function of the relative angle of impingement - which in turn is a function of the velocity difference between belt speed and particle velocity.

Sounds complicated. But no more complicated than, say, frictional loss through bends and fitting in a pipe flow system. We provide our pipe designers information to guide them. Why don't we do the same for our conveyor designers?

A basic study of chutes as "flow weirs" would provide much useful information to our chute designers.

Until such design data becomes more readily available we are forced to make some basic design assumptions.

11. Turbulence decreases Bulk Density

At points of turbulence the effective thickness of the flow stream will increase. That is, the local bulk density will decrease. But by how much? A factor of 4, 6 or 10? What is your experience? How far along the belt does this turbulence continue?

Can turbulence occur inside the chute? What effect does it have on flow through the chute? Make some realistic estimate of the local bulk density. It will help you to visualise, in a practical way, what happens to the material flow inside the chute.

At which section does the chute become a flow orifice? If not an orifice, then where does the chute shape the stream flow - creating a "flow weir" or constriction?

In many cases the increase in flow stream depth is seriously underestimated. Our chute designers don't fully appreciate the extent of the "bulking-up" at points of turbulence.

The result? Spillage!

What is the experience of our commissioning engineers?

"The sides of the oversize chute after the secondary scalping screen were raised by 300 mm to prevent spillage".

"Side plates were raised by 150 mm to prevent spillage".

"Due to excessive spillage it was necessary to fit side skirts to the areas between all screen discharge chutes, and to extend the skirting for some distance beyond the last feed point. IMPROVED CHUTE DESIGN could have eliminated these problems".

"In one design the receiving bin's outlet was set approximately 1,5 m from the head of the apron feeder, with no side plates along the path. This would have resulted in large amounts of spillage over the sides of the apron feeder".

"Excessive spillage was noted at the 'tilt' type feed chutes from the secondary crusher feed bins".

The problem of spillage requires more attention to material flow paths.

"The design of spillage trays below the head pulleys of many conveyors proved unsatisfactory and had to be revamped. The common fault with them was that they were too short and too shallow".

"The dribble chute was too small and did not fully enclose the squeezer. The dribble chute fouled on the squeezer plummer blocks and shafts".

"The spillage chute at the head end of the conveyor does not extend far enough back. Slimes from the head end drip down onto the concrete base and require frequent cleaning".

12. Friction in long chutes

In chutes of rectangular cross-section the major portion of the friction losses are due to particles sliding against the chute bottom. These losses are in the order of 82%. The remaining losses arise from particles sliding against the side walls of the chute - say 9%.

The total frictional drag is given by:

$$F = u N (1 + K \frac{H}{B}) \quad (5)$$

where u is the coefficient of wall friction
 N is the total normal force per unit length
of chute bottom at the section considered.
 K is the active pressure coefficient.
(The ratio of lateral to normal pressure
at the wall).

The frictional drag increases as the width of the chute is reduced.

Frictional drag will control flow in open channels at low inclination angles, close to the angle of repose of the material on the chute surface. Under these conditions the discharge rate is controlled by the chute rather than by the bin orifice.

For steady, fully developed, constant velocity flow the chute inclination angle, measured from the horizontal, should be between the angle of repose and the dynamic internal friction angle. Studies on millet seed and polythene particles have shown that lower and upper chute inclination bounds exist within which constant velocity flow occurs. These angles of inclination differ by about 4° . Outside this narrow range flow is either accelerated or choking.

13. Round Bottom Chutes

The simplest type of chute has a flat bottom welded to vertical sides. The outlet is reduced to suit the width of the belt which the chute is required to feed.

In an alternative design the bottom changes progressively from the flat plate at the mouth of the chute to a concave section where it delivers on to the next belt.

The round bottom ensures that the material will leave the chute lip in the centre - thereby providing the ideal feed to the next link in the conveying system.

The round bottom also reduces the total frictional drag - thereby reducing the angle at which the material will continue to flow without choking. The advantages are even more pronounced where the chute is required to negotiate a change of angle in plan. Round bottom chutes will often convey small materials successfully around considerable angles in plan, at inclinations equal to the flat bottom straight chutes for large material.

For example, coal in round bottom chutes will negotiate curves in a smooth, unbroken stream, causing little damage to the chute and reducing the degradation of the coal. If the change of angle is negotiated on flat-bottom plates, accompanied by a succession of kinks in the side plates, degradation is often severe. The headroom required to incorporate the flat-bottom chute is greatly increased.

14. Maintenance Access

Chute designers frequently fail to give serious consideration to the need for maintenance access.

"It was not possible to get into the chute without entering from the crusher side", complained one commissioning engineer. "Easily removable, clamp-down type chute covers were fitted on site".

"In many cases chutes were constructed so small that access is very limited. The clear distance between the head pulley and the front chute plate is inadequate on the stockpile conveyor. The front liner plate has worn through. Access to the liners on the lower half is extremely difficult for maintenance purposes. An inspection door on the front of the chute is necessary".

"In general the transfer chutes throughout the HMS plant lack access doors and removable panels. This makes maintenance very difficult and replacement of liners impossible."

15. Wear of Chutes

Apart from maintenance access for replacement of liner plates, other aspects of chute wear should be considered at the design stage.

"Dead boxes were fitted into the head chutes to overcome high wear on the liners. This should have been incorporated in the initial design."

"Angle-iron was welded onto the sloping portions of numerous chutes to increase plate life. Angle iron 'ribs', welded into screen discharge chutes, conveyor transfer chutes, etc., to prevent wear of liners and plates, are most beneficial."

"Dead boxes are NOT desirable in a SAMPLING plant since they are potential hang-up points. Consequently many of the chutes have potential high wear points."

"Because of the high rate of wear experienced on the plant", explained one commissioning engineer, almost all chutes have been modified. The modifications included the fitting of dead boxes at conveyor discharge points, redesign of chutes, and the fitting of angle iron strips in the chutes". (What a commentary on the original chute design!!)

16. Conclusion

Considerable time and money is spent fixing up conveyor chutes on site, because the original chute design was a hit-and-miss job. The plate work draughtsman did his best but without adequate engineering support.

This initial study by the Bionic Research Institute highlights the main problem areas, and shows that chute design can be based on rational design procedures. Some very basic material tests should be conducted to give the designer tangible design information. Further information on test procedures and design methods is available free on request from the Bionic Research Institute, P.O. Box 93432, Yeoville 2143, Republic of South Africa (incorporated as a non-profit making organisation).

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