Performance Characteristics of Reciprocating Plate Feeders

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SUMMARY The advantages and disadvantages of reciprocating plate feeders are reviewed and the performance characteristics of two types of plate feeders are analysed. The Shear Gate type Plate Feeder employs a conventional plane-flow hopper in which the feeding action depends on the development of a shear plane in the bulk solid. This type of feeder is limited to use with bulk solids of controlled particle size. The Open Front type Plate Feeder involves the total movement of the mass of the solid on the plate during the forward stroke, with feeding being dependent on funnel flow in the rear portion of the hopper. This type of feeder is relevant to the handling of ROM containing large lumps. In both cases, feeding takes place during each return stroke of the plate. Design equations for both types of feeders are presented.

1. INTRODUCTION

Feeders play an important role in bulk solids handling operations in providing controlled flow of solids in various parts of handling plant. There are several types of feeders which incorporate various operating principles to achieve the feeding function; their selection depends on the such factors as the scale of operation, the properties of the bulk solid, the nature of the handling task and the details of the handling plant in which the feeder forms an integral part. For any feeder installation, it is most important, at the design stage, that the flow characteristics of the bulk solid be known and the interactive roles of the hopper and feeder be fully understood.

The subject of feeder loads and performance has received significant attention in recent years and a selection of papers dealing with this subject are listed in the references at the end of this paper, (Ref.[1-5]). One type of feeder about which there is an apparent lack of published information concerning its performance characteristics is the reciprocating plate feeder. Such feeders have a particular application in the mining and mineral processing industries, but their use to date has been somewhat limited. However there is growing interest by some industries in their use and this has prompted the current research programme which is aimed at establishing performance criteria and design recommendations for this type of feeder [6].

Reciprocating plate feeders operate at quite low frequencies. The type of bulk material being handled determines the hopper configuration and geometry, the feeding mode and the shear forces required to drive the plate on its forward and return strokes. The two basic feeding modes considered in this paper are associated with the following feeder types:

(i) Shear gate plate feeders
(ii) Open front ROM (Run-of-mine) plate feeders

The shear gate feeder incorporates a conventional type hopper and shear gate, while the open front hopper is designed to accommodate large variations in bulk solid lump size as occurs in the case of ROM ores.

The paper analyses the mechanics of the feeding action, concentrating on the determination of feeder loads and driving forces. The analysis is compatible with field observations and incorporates the relevant flow properties of the bulk solid being handled.

2. PLATE FEEDERS - GENERAL COMMENTS

Plate feeders are different from other feeders in some very important ways:

- Feeding is discontinuous
- The hopper cannot be emptied by the feeder.
- Feeder operation relies more on bulk solid properties and on surface friction properties than other feeders.

The discontinuous feed results from the reciprocating motion of the plate, with feeding taking place during the return stroke only. The discharge chute from a plate feeder becomes an important component in assisting to smooth flow surges to downstream processes or conveyors. The non-uniformity of the feed means that the width of the feeder needs to be larger than that of the equivalent apron feeder; in the latter case, the feeder width is governed by the minimum arching dimension and the need to achieve the required steady flow rate.

Despite the foregoing characteristics which may be perceived as shortcomings, plate feeders offer some advantages over other feeder types, particularly in the case of large scale bulk solids handling operations. The main advantages are:

- Generally lower capital cost.
- Reduced damage from large lumps.
- Reduced spillage.
- Lower maintenance and operating costs.
- Short delivery time.

2.1 Capital Cost

For large installations in ROM operations, it is generally reported that plate feeders offer significant cost advantages over unidirectional feeders for an equivalent service. This is related, largely, to the simplicity of plate feeders in terms of both their fabrication and operation. The plate which may be stepped or flat is simply supported on rollers guided in a supporting track.

2.2 Damage from Large Lumps

Damage to feeders in ROM operations result from two main sources:

(i) Impact from dumping method.
(ii) Wedging action at shear gate or along slot.

Plate feeders are equipped to handle the arduous conditions with limited maintenance.

2.3 Impact

In ROM operations, the lump size depends on the ore body, mining method and loading procedure. Often the maximum lump size is dictated by the size of the handling equipment such as a shovel or haul truck. Lumps greater than 1500 mm are normal, with lumps up to 2,500 mm not uncommon. The potential damage from large lumps falling into a hopper and onto a feeder can only be minimised by providing some protection from the ore itself. This is where the plate feeder has a distinct advantage in that the hopper cannot be emptied, thus offering a cushion of material to protect the feeder. On the other hand, in the case of apron feeders, while elaborate control methods are often installed to prevent feeders in ROM operations from emptying the hopper, it is not uncommon for plant operators to override the controls, causing the hopper to empty. The feeder is then exposed to impact damage.

2.4 Wedging Damage

Wedging damage from large lumps is more common in shear gate hoppers than open fronted hoppers. It is common for belts in belt feeders to be damaged by wedging of large lumps at the hopper opening. Apron feeders have been known to crack pans from wedging at the shear gate as well as wedging of large particles along an incorrectly designed hopper slot opening.

2.5 Spillage

Spillage from feeders has always been a cause for concern, particularly in areas of poor access such as reclaim tunnels and loading vaults. Plate feeders have a distinct advantage due to their feeding action insofar as there is no "carryback" of material. Belt feeders require a cleaner or scraper, while apron feeders generally come equipped with a spillage conveyor (which should then be provided with a scraper). The amount of spillage depends to a large degree on the bulk material properties and the operating conditions, but generally plate feeder operate with minimum spillage. Skirtplates are able to be set close to the smooth plate surface to contain small particles.

2.6 Maintenance and Operating Costs

Modern plate feeders use hydraulic cylinders to achieve the feeding motion. The plate itself has no moving parts and consists of a continuous fabricated steel plate with stiffening on the underside to provide longitudinal, lateral and torsional rigidity. The plate is supported on rollers which run in tracks mounted under and inboard of the plate edges such that material cannot normally become entrapped in the tracks to foul movement. Motion of plate feeders is generally in the range of ±150mm to ± 500 mm and may stroke at a rate of 6 to 20 strokes/minute. Operating costs associated with spillage control and damage from large lumps are substantially reduced. In some installations there is a reduction in cost associated with spares holdings.

2.7 Delivery

Due to simplicity of construction and off-the-shelf components, short delivery times can be achieved. This is sometimes attractive for 'fast-track' engineering projects.

3. SHEAR GATE PLATE FEEDERS

A typical shear gate plate feeder is shown in Figure 1. This type of feeder is suited to materials which have a controlled particle size such as product from primary or secondary crushing. This is to ensure that jamming will not occur in the feed zone. ROM material, which may contain large lumps, is not suitable for shear gate feeding. Cohesive bulk materials, which are abrasive in nature, can be successfully handled with a plate feeder. However successful operation depends a great deal on the material properties.

Figure 1 shows the plate feeder as it would operate on the forward stroke. The feeding action is similar to that of a belt or apron feeder except no feeding occurs. The material below the shear plane moves forward with the plate to the end of the forward stroke. For this to occur efficiently, without slip along the feeder plate, all of the shear occurs along a shear plane within the body of material. The use of a plate having a stepped surface profile as illustrated in Figure 1 can assist the operation.

For the return stroke, the plate slides relative to the bulk solid as illustrated in Figure 2. Feeding takes place during this stroke.

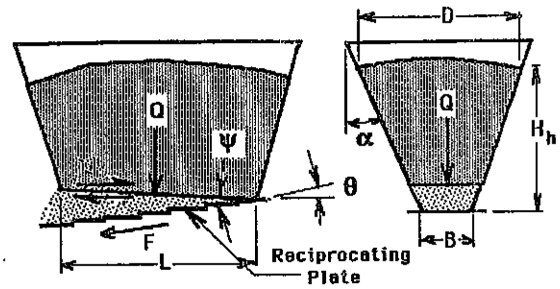

Figure 1. Shear Gate Plate Feeder - Forward Stroke

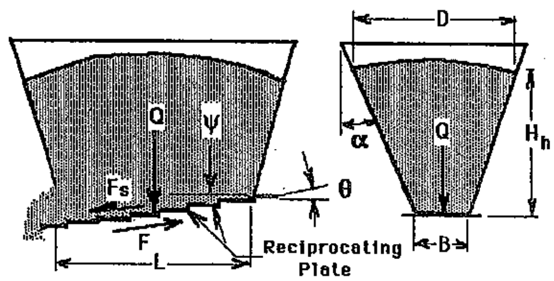

Figure 2. Shear Gate Plate Feeder - Return Stroke

The driving force to be exerted by the plate in shearing the bulk solid on the shear plane is

$$F = \mu_E Q \tag{1}$$

Where μ_E = Equivalent Friction
Q = Vertical Load on Feeder

The determination of the vertical load Q has been well documented for mass-flow hoppers [1-2], the procedures being reviewed in Section 5. In the case of funnel-flow hoppers, the procedures require adaptation based on an assessment of the hopper geometry, the flow pattern and the bulk solid flow properties.

3.1 Equivalent Friction - Forward Stroke

During the forward motion of the plate, the feeder operates in a similar mode to that of an apron feeder for which the forces involved are indicated in Figure 3. An analysis of the forces acting in the feed zone leads to the following expression for the equivalent friction:

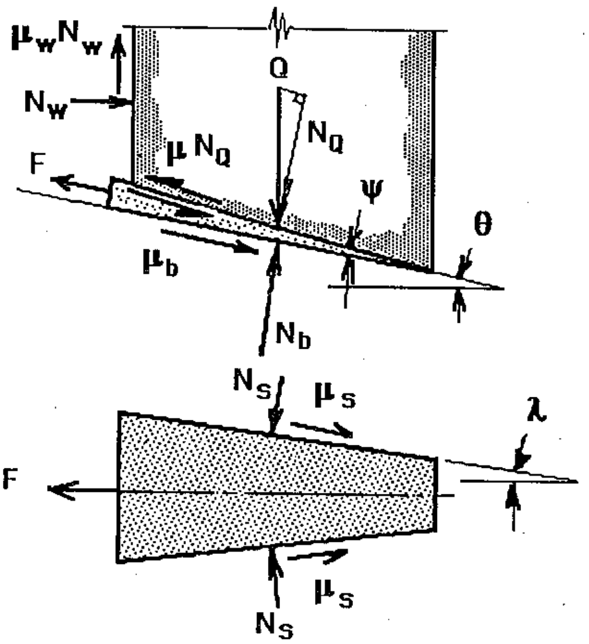

Figure 3. Mechanics of Feeder Operation - Forward Motion

$$\mu_E = \frac{\mu \cos \psi - \sin \psi}{\cos(\psi \pm \theta)[1 + \mu \mu_w] + \sin(\psi \pm \theta)[\mu - \mu_w]} \quad (2)$$

where θ = Conveyor slope angle
ψ = Release angle
μ_w = Friction coefficient on end wall of hopper
μ = Coefficient of internal friction on shear plane

+ sign corresponds to an inclined feeder
- sign corresponds to a declined feeder as shown in Figure 1

Experience has shown that the friction angle on the shear plane may be estimated from

$$\mu = \sin \delta \quad (3)$$

Alternatively, μ may be determined from

$$\mu = \tan(\phi_t) \quad (4)$$

where δ = Effective angle of internal friction of bulk solid
ϕ_t = Angle of internal friction of bulk solid on shear plane

Equation (4) will normally give an upper bound value of μ.

Special case:

When the friction of the end wall has negligible effect; i.e. $\mu_w = 0$.

$$\mu_E = \frac{\mu \cos \psi - \sin \psi}{\cos(\psi \pm \theta) + \mu \sin(\psi \pm \theta)} \quad (5)$$

A typical set of design curves based on equations (4) and (5) are shown in Figure 4.

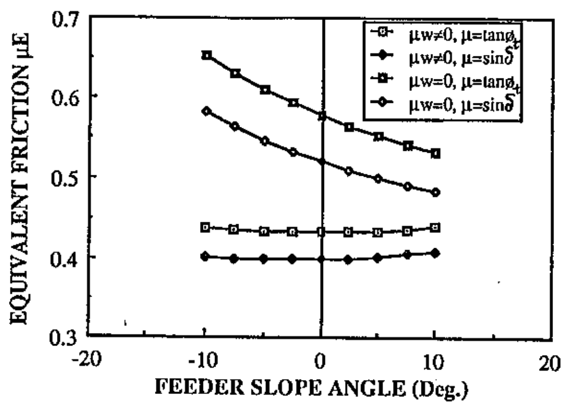

Figure 4. Typical Curves for μ_E for Forward Stroke Showing Influence of Slope Angle θ
$\psi = 10^\circ$; $\phi_w = 30^\circ$; $\phi_t = 40^\circ$; $\delta = 50^\circ$

3.2 Equivalent Friction - Return Stroke

On the return stroke the bulk solid is compressed against the rear wall of the hopper; the bulk solid must slip relative to the surface of the plate as shown in Figure 2. Under these conditions, the equivalent friction is given by

$$\mu_E = \frac{\mu \cos \psi + \sin \psi}{\cos(\psi \pm \theta)[1 - \mu \mu_w] - \sin(\psi \pm \theta)[\mu + \mu_w]} \quad (6)$$

Under normal conditions a shear plane will not develop within the bulk solid. Rather there will be shear of the bulk solid along the surface of the feeder plate as it slides relative to the bulk solid. For this condition, the equivalent friction for the return stroke is given by

$$\mu_E = \frac{\mu_s}{\cos(\pm\theta) - \mu_s \sin(\pm\theta)} \quad (7)$$

Where $\mu_s = \tan \phi_s$, ϕ_s being the surface friction angle for the plate

If the hopper and plate are constructed from the same material, $\phi_s = \phi_w$

A typical set of design curves based on equations (6) and (7) are shown in Figure 5.

The cases described when $\mu = \tan \phi_t$ and $\mu = \sin \delta$ occur after periods of undisturbed contact with the feeder. It has been shown [7] that after periods of undisturbed contact of moist bulk solids, there is a reaction which takes place at the interface which leads to the formation of an adhesive or cohesive bond. This condition must be considered when estimating loads on plate feeders, but it does not effect the loads on apron or belt feeders.

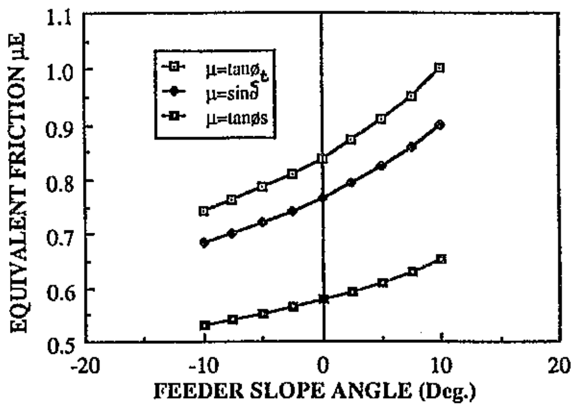

Figure 5. Typical Curves for μ_E for Return Stroke Showing Influence of Slope Angle θ
$\psi = 10^o$; $\phi_w = 30^o$; $\phi_t = 40^o$; $\phi_s = 30^o$; $\delta = 50^o$

The choice of the appropriate friction factor should take account of the period of undisturbed contact and the amount of build-up of material on the plate. The expression $\mu = \sin\delta$ is based on experience with plate feeders and applies when a definite shear plane has developed during the forward stroke. The expression $\mu = \tan\phi_t$ would apply when pronounced build-up occurs after prolonged undisturbed contact. It gives the upper bound value for μ.

3.3 Total Driving Forces - Forward Stroke

The total driving force on the forward stroke is determined from the sum of several forces.

(a) Skirtplate Drag

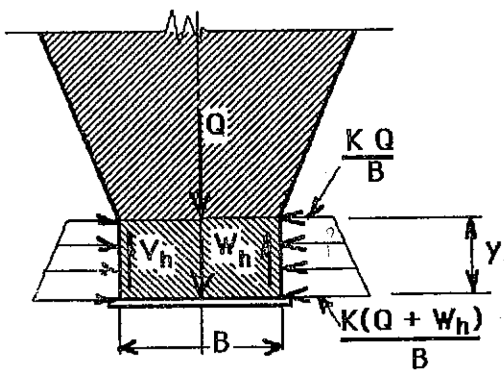

Figure 6. Pressure Distribution for Skirtplate Section

The pressure distribution for the skirtplate section under the hopper is shown in Figure 6. Neglecting the vertical support V_h due to the skirtplates, the skirtplate resistance is given by

$$F_{sph} = \mu_2 K (2Q + \rho g B L y_h) \frac{y_h}{B} \quad (8)$$

where Q = Feeder load
ρ = Bulk density
y_h = Average height of material against skirtplates
K = Ratio of lateral to vertical pressure at skirtplates
g = Acceleration due to gravity = 9.81 (m/s^2)
B = Width between skirtplates
μ_2 = Skirtplate friction coefficient
L = Total length of skirtplate (m)

It should be noted that, the skirtplates may be diverging. Hence the frictional resistance will be less than in the case of parallel skirts. From a force analysis, μ_2 may be estimated from

$$\mu_2 = \frac{\mu - \tan\lambda}{1 + \mu \tan\lambda} \quad (9)$$

where λ = Half divergence angle of skirtplates
μ = Friction coefficient for skirtplates

The pressure ratio K_v is such that $0.4 \leq K_v \leq 1.0$. The lower limit may be approached for initial start-up and the upper limit for steady flow. In the case of slow feed velocities, as is relevant to plate feeders, the value of K_v for flow may be in the middle range.

(b) Plate Drive Resistance

$$F_b = [(Q + \rho g B L y_h) y_h \mu_b + w_b L_b \mu_b] \cos\theta \quad (10)$$

where μ_b = Roller friction
w_b = Plate weight per unit length
L_b = Plate length

(c) Force to Accelerate Material

$$F_A = Q_m v \quad (11)$$

where Q_m = Mass flow rate
v = Average plate velocity on forward stroke

It is assumed that

$$Q_m = \rho B y_h v \quad (12)$$

Usually the force F_A is negligible.

(d) Total Resistance

The total resistance is the sum of all resistances. That is

$$F = \Sigma_j F_j \quad (13)$$

The condition for non-slip between the plate and bulk solid under steady motion can be determined as follows:

$$\mu_B (Q + W_h) > (F_h + F_{sph}) \quad (14)$$

where

$$\mu_B = \mu_s \cos\theta + \sin\theta \quad (15)$$

3.4 Total Driving Forces - Return Stroke

For the return stroke, in addition to the force to shear the plate relative to the bulk solid, the resistance due to the plate moving against the support rollers must be included. Equation (10) also applies for this case.

4. OPEN FRONT PLATE FEEDER

The open front type plate feeder is used in ROM applications where there is little control over maximum lump size. The forward and return strokes of this type of feeder are illustrated in Figures 7 and 8 respectively.

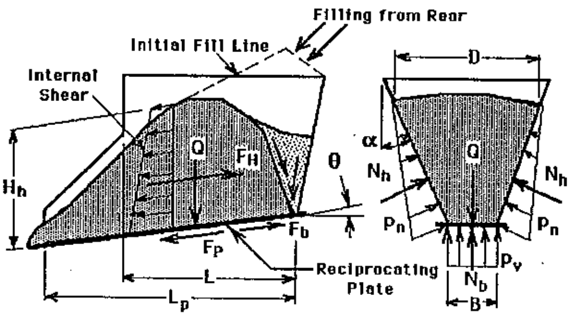

Figure 7. Open Front Plate Feeder - Forward Stroke

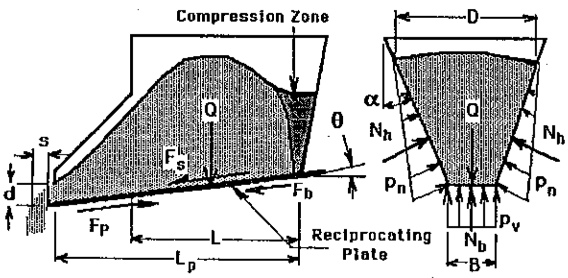

Figure 8. Open Front Plate Feeder - Return Stroke

In this case, the front sloping wall of the hopper allows a feeding action to take place essentially without internal shear of the bulk solid. During the forward stroke, the whole mass moves forward creating a cavity at the back of the hopper as illustrated in Figure 7. This then allows bulk material to slough off from the top surface to fill the cavity. The movement of the bulk mass during the forward stroke is resisted only by the drag against the side walls of the hopper.

During the return stroke the bulk mass is compressed against the back wall of the feeder and the plate slides against the frictional resistance offered by the plate surface. This is shown in Figure 8.

In order to obtain efficient feeding, it is necessary to fill the dump hopper from the rear. This produces the initial fill profile indicated in Figure 7. Also, it is quite evident that the feeding operation depends on the continual filling of the back cavity during the forward stroke. This is essential in order to provide the necessary resistance to allow the plate to move relative to the bulk solid mass during the return stroke. Once the cavity at the rear of the hopper remains empty, then the whole bulk solid mass oscillates forwards and backwards with the plate with no feeding taking place. For this reason it is not possible to empty the feed hopper. It is also noted that the feeding action reduces in efficiency when the bulk solid filling the back cavity is highly compressible.

4.1 Frictional Resistance during Forward Stroke

During the forward stroke, frictional resistance due to sliding against the side walls of the hopper as well as due to internal shear must be overcome.

(a) Frictional Resistance due to Sliding Against Hopper Walls

In order to move the bulk mass forward, the frictional drag is imposed by the hopper walls. In view of the peaked stress field that would occur in this case, the pressure distribution around the hopper boundaries is as indicated in Figure 7.

The force to overcome the friction due to the stored bulk solid is

$$F_{H1} = \frac{2 \mu_w L}{\cos \alpha} \int_0^{H_h} p_n \, dz \qquad (16)$$

where

$$p_n = \gamma K \left(\frac{h_o - z}{n - 1} + \left[h_c - \frac{h_o}{n - 1} \right] \left[\frac{h_o - z}{h_o} \right]^n \right) \qquad (17)$$

Where h_c = surcharge head acting at hopper transition
h_o = height of transition from intersection point of hopper sides

The relevant parameters in equation (17) are showm in Figure 9

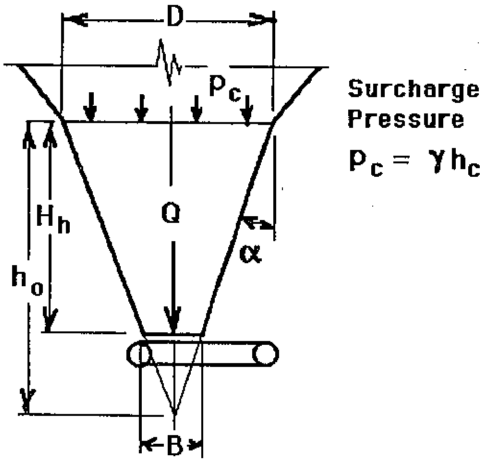

Figure 9. Hopper Details

For open dump hopper $h_c = 0$

The factor 'K' in equation (17) is the ratio of normal pressure at the hopper wall to the vertical pressure. That is

$$K = p_n / p_v \qquad (18)$$

From an analysis of the stress fields, the expression for 'K' is given by

$$K = (n + 1) \left[\frac{\tan \alpha}{\tan \alpha + \tan \phi} \right] \qquad (19)$$

where α = Hopper half angle
ϕ = wall friction angle

The value of 'n' depends on the stress field developed. For a peaked stress field, n = 0. Normally n > 0, having a maximum value when an arched stress field exists. For the case of the plate feeder of the type shown in Figure 7, it is more likely that a peaked stress field will exist.

Special Case - Dump Hopper

It may be shown that in this case the hopper wall resistance F_{H1} is given by

$$F_{H1} = \mu_{E1} Q \qquad (20)$$

For the case under consideration, K will have a minimum value which corresponds to n = 0. The equivalent friction is

$$\mu_{E1} = \left(\frac{\mu_w K}{\cos\alpha}\right)\left(\frac{H_h}{B}\right) \qquad (21)$$

H_h = Average height of stored bulk solid in hopper

$\mu_w = \tan\phi_w$ = Friction Coefficient at the wall

α = Hopper half-angle

ϕ_w = Wall friction angle

The variation of equivalent friction with wall friction is illustrated in Figure 10.

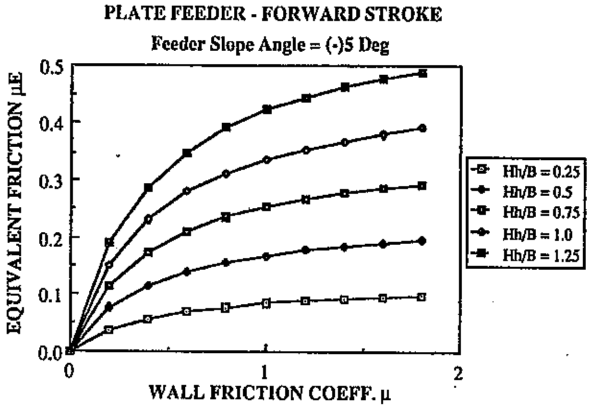

Figure 10. Equivalent Friction for Side Wall Drag - Forward Stroke

(b) Effect of Internal Shear

If internal shear takes place as illustrated in Figure 6, it may be shown that the the frictional drag is given by

$$F_{H2} = 2 L \mu_g \left[\int_0^{p_{h}} [(H_h - z)\tan\alpha + \frac{B}{2}]\, dp_z - \int_0^{H_h} p_z \tan\alpha \, dz \right] \qquad (22)$$

The foregoing assumes internal shear across the feeder. In practice this is unlikely to be the case, a fact confirmed by field observations. If internal shear takes place, it is more likely to be limited to the outer zones of the bulk solid, that is, a boundary layer effect. This is illustrated in Figure 11.

Special Case - Dump Hopper

It may be shown that, in this case, the drag force F_{H2} due to internal shear is given by

$$F_{H2} = \mu_{E2} Q \qquad (23)$$

where

$$\mu_{E2} = k_E \mu_g \qquad (24)$$

μ_g = Coefficient of internal friction

The value of k_E will depend on the degree of internal shear. For fully developed shear and no 'boundary layer' effect.

$$k_E = 1.0$$

Fully developed shear may only be approached in the case of loosely consolidated bulk solids with low cohesion. In most cases the shear will not be fully developed and $k_E < 1.0$; it is more likely that $k_E < 0.5$. For very cohesive, highly consolidated bulk solids, the bulk solid will move more as a solid block and, in this case, $k_E \rightarrow 0$.

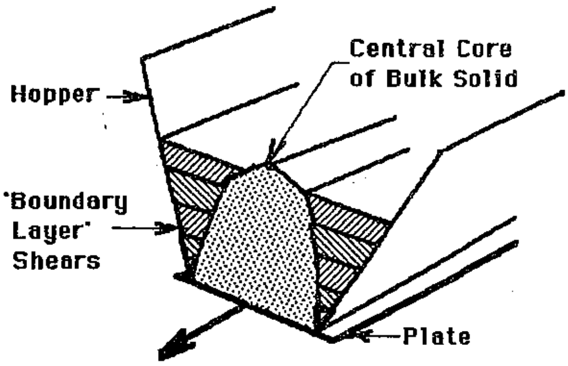

Figure 11. Build -Up on Plate and 'Boundary Layer' Effect

(c) Total Equivalent Friction

On the basis of equations (20) and (23), the 'total' equivalent friction is given by

$$\mu_E = \mu_{E1} + \mu_{E2} \qquad (25)$$

4.2 Frictional Resistance during Return Stroke

The action during the return stroke is similar to that of the shear gate plate feeder. The equivalent friction is given by equations (5) and (6)

4.3 Total Resistances

For the forward stroke, the force to drive the pan forward is

$$F_P = F_H + F_b + F_a \qquad (26)$$

Where

$$F_H = F_{H1} + F_{H2} \qquad (27)$$

F_b is the resistance to move the plate relative to the support rollers and is given by

$$F_b = \mu_b (Q + w_b L_b) \cos\theta \qquad (28)$$

where μ_b = Plate support roller friction

w_b = Plate weight per unit length

L_b = Length of plate feeder

F_a is the inertia force due to the acceleration of the bulk mass on the plate. That is

$$F_a = M_T \, a \qquad (29)$$

where M_T = Total effective mass of bulk solid moving with the plate

a = Plate acceleration during forward stroke

The plate acceleration will depend on the characteristics of the drive. A common wave form will be sinusoidal. That is

$$a = X\,\omega^2 \cos \omega t \qquad (29a)$$

where $X = {}^{(stroke)}/_2$

ω = circular frequency

4.4 Feed Rate

The feed rate is governed by the effective cross-sectional area of the bulk solid on the plate at the discharge end and the plate stroke. The feed rate is expressed by

$$Q = \frac{3600\,\rho\,A\,S}{T} \quad t/h \qquad (30)$$

Where A = Effective cross-sectional area (m^2)
ρ = Bulk density (t/m^3)
S = Feeder stroke (m)
T = Plate cycle time (s)

The effective area A may be expressed as

$$A = c\,B\,d \qquad (30a)$$

Where B = Feeder width (m) (Figure 8)
d = Average depth of feed (m) (Figure 8)
c = Feeding efficiency factor, $c \le 1$

For fully developed feed across the plate, c = 1.0
If there is build-up of bulk solid on the plate, c < 1.0

5. FEEDER LOAD Q

5.1 Mass-Flow Hoppers

For a wedged-shaped mass-flow hopper, the vertical load Q is given by

$$Q = q\,\gamma\,L\,B^2 \qquad (31)$$

Where q = non-dimensional surcharge factor
$\gamma = \rho\,g$ = bulk specific weight
ρ = bulk density
L = length of slotted opening
B = width of slot or diameter of circular opening

Based on an analysis of the pressure distribution in the hopper, it may be shown that the vertical pressure acting at the hopper outlet is

$$p_o = \gamma \left\{ \frac{B}{2\,(n-1)\tan\alpha} \left[1 + (2\,h_c\,(n-1)\tan\alpha - D)\left(\frac{B^{(n-1)}}{D^n}\right) \right] \right\} \qquad (32)$$

where D = Diameter or width of hopper at transition

$h_c = p_c/\gamma$,

p_c being the surcharge pressure acting at the transition

The exponent 'n' in equation (32) is given by

$$n = K \left(1 + \frac{\tan\phi}{\tan\alpha} \right) - 1 \qquad (33)$$

where K is the ratio of normal pressure at the hopper wall to the corresponding vertical pressure

The general expression for the non dimensional surcharge pressure may be obtained. That is,

$$q = \frac{1}{2\,(n-1)\tan\alpha} \left\{ 1 + [\,2\,(n-1)\,h_c \tan\alpha - D\,] \frac{B^{(n-1)}}{D^n} \right\} \qquad (34)$$

Two cases are of importance, the initial filling condition and the flow condition.

(i) <u>Initial Filling Condition</u>

This applies when the feed bin is initially empty and then filled while the feeder is not operating. Research has shown that the initial filling loads can vary substantially according to such factors as

(i) Rate of filling and height of drop of solids as may produce impact effects.

(ii) Uniformity of filling over the length and breadth of the feed bin; asymmetrical loading will produce a non-uniform pressure distribution along the feeder.

(iii) Clearance between the hopper bottom and feeder surface.

(iv) Degree of compressibility of bulk solid

(v) Rigidity of feeder surface

For the initial filling condition the stress field in the hopper is peaked; that is, the major principal stress is almost vertical at any location. The determination of the initial surcharge factor q_i can be made by using an appropriate value of 'n' in equation (34). The following cases are considered:

(a) For a totally incompressible bulk solid and a rigid feeder with minimum clearance, the upper bound value of q_i may be approached. The upper bound value corresponds to n = 0.

For this value of n, equation (34) becomes

$$q_i = \left\{ \frac{1}{2\tan\alpha} \left[\frac{D}{B} + \frac{2\,h_c \tan\alpha}{B} - 1 \right] \right\} \qquad (35)$$

(b) For a very incompressible bulk solid and a stiff feeder, n = 0.1

(c) For a very compressible bulk solid and a flexibly supported feeder, n = 0.9

(d) For a moderately compressible bulk solid stored above a flexibly supported feeder, n = 0.45

While the value of q_i may be determined using an appropriate value of n in equation (34), from a practical point of view, it has been established that a satisfactory prediction of q_i may be obtained from

$$q_i = \left\{ \frac{1}{2\tan\alpha} \left[\frac{D}{B} + \frac{2\,h_c \tan\alpha}{D} - 1 \right] \right\} \qquad (36)$$

The vertical load Q_i is given by

$$Q_i = q_i\,\rho\,g\,L\,B^2 \qquad (37)$$

It should be noted that the open front type plate feeders receive little load support from the side walls. This is due to the localised funnel-flow feeding action that occurs at the rear of the hopper. An arched stress field is not expected to develop along the length of the feeder slot and, therefore, the reduced loads that accompany this type of stress field will not occur. For the purpose of completeness in the design of shear gate feeders, the procedures for determining the loads occuring under flow conditions are included.

(ii) Flow Condition

Once flow has been initiated, an arched stress field is set up in the hopper. Even if the feeder is started and then stopped, the arched stress field in the hopper is preserved. In this case, the hopper is able to provide greater wall support and the load on the feeder, together with the corresponding drive power, is significantly reduced. While equation (34) may be applied by choosing an appropriate value of 'n', some difficulty arises due to the redistribution of stress that occurs at the hopper / feeder interface. In the case of a feeder with, theoretically, zero clearance between the hopper outlet and feeder surface, the value of 'n' may be based on the maximum value of 'K' substituted in equation (33). The method of determining the maximum value of K is described in Ref. [1]. However, it has been found that once a flow stress field has been established, there is some redistribution of the stress field in the clearance space between the hopper and the feeder. Research has shown that the load on a feeder may be estimated quite satisfactorily on the basis that the major principal stress or pressure at the hopper outlet acts vertically downward. Using this approach, the non-dimensional surcharge factor q_f is given by [1],

$$q_f = \frac{Y(1+\sin\delta)}{2(X-1)\sin\alpha} \qquad (38)$$

where α = Hopper half angle
δ = Effective angle of internal friction.

X and Y are given by equations (39) and (40) respectively.

$$X = \frac{\sin\delta}{1-\sin\delta}\left[\frac{\sin(2\beta+\alpha)}{\sin\alpha} + 1\right] \qquad (39)$$

where

$$Y = \frac{(\beta+\alpha)\ \sin\alpha + \sin\beta\ \sin(\beta+\alpha)}{(1-\sin\delta)\sin^2(\beta+\alpha)} \qquad (40)$$

$$\beta = \frac{1}{2}\left[\phi + \sin^{-1}\left(\frac{\sin\phi}{\sin\delta}\right)\right] \qquad (41)$$

$\phi = \tan^{-1}\mu$, where ϕ = wall pressure angle
δ = effective angle of internal friction

The total feeder load is given by

$$Q_f = q_f \rho\, g\, L\, B^2 \qquad (42)$$

5.2 Funnel Flow Hoppers

In ths case the load Q may be estimated by using equation (36) and (37) and making some assumptions about the size and shape of the flow channel in the hopper.

6. EXAMPLE

Consider an Open Front Type Plate Feeder in which the following details apply:

Bin and Feeder:		
Opening dimension	B	= 2.0 m
Average height	H_h	= 2.2 m
Effective Length of hopper	L	= 6.0 m
Length of plate	L_b	= 9.0 m
Weight of plate	w_b	= 0.4 t/m
Feeder slope	θ	= - 5°
Plate idler friction	μ_b	= 0.06
Hopper half-angle	α	= 30°
Bulk Solid:		
Bulk density	ρ	= 1 t/m³
Effective angle of internal friction	d	= 50°
Wall friction angle for hopper	ϕ	= 30°
Internal Friction angle	ϕ_t	= 40°
Friction angle for bulk solid on plate	ϕ_s	= 30°

(a) Forward Stroke

From (19)	K	= 0.5
From (21)	μ_{E1}	= 0.37
	μ_g	= tan 40° = 0.84
Assume	k_E	= 0.2
From (24)	μ_{E2}	$= k_E \mu_g$ = 0.17
From (36)	q	= 1.09
From (37)	Q	= 257 kN
From (20)	F_{H1}	= 84 kN
From (23)	F_{H2}	= 44 kN
Hence	F_H	= 128 kN
From (28)	F_b	= 18 kN

Neglecting the acceleration; that is, the average force to drive the plate on the forward stroke is

F = 146 kN

(b) Return Stroke

Assuming plate slips relative to bulk solid on return stroke

From (7)	μ_E	= 0.55 (lower bound)
	μ_E	= 0.72 (average)
	μ_E	= 0.78 (upper bound)
From (1)	F_H	=144 kN (lower bound)
	F_H	= 189 kN (average)
	F_H	= 204 kN (upper bound)
From (28)	F_b	= 18 kN

Again neglecting the acceleration; that is, average force to drive plate on return stroke

F = 162 kN (lower bound)
= 207 kN (average)
= 222 kN (upper bound)

7. CONCLUDING REMARKS

The analysis presented in this paper is based on current research into feeder loads with specific reference to plate feeders. Such feeders, while not commonly used in the past, are attracting increased interest. Future work will concentrate on experimental studies on a model plate feeder as well as field observations. The results will be used to refine the theory and provide general design recommendations.

The analysis and field results correlate well considering the variables involved in large scale operations. The need for designers of plate and other feeders to give careful consideration to the hopper configuration and the material flow properties cannot be too strogly emphasised.

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