

# CONSIDERATIONS FOR MATERIALS HANDLING STORAGE DESIGN

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## 1. INTRODUCTION

For many years, mining plants have been operating with various problems of differing degrees of severity plaguing the storage and handling of their bulk materials. Vast amounts of time and money have been lost due to downtime, sub quality products, damage to equipment and excessive wear in hoppers and chutes, simply as a result of the lack of understanding the behaviour and flow characteristics of bulk materials under handling, storage, reclaim and feeding conditions. Building new plants and the expansion of existing plants are expensive and due to the prevailing fragile economic situation in the mining and allied industries, it is often difficult to allow for bulk solids flow testing and advanced functional design of materials handling systems at the early conceptual stage. Material flow testing and tests on physical models, are critical in order to define design parameters for bins, transfer chutes, silos and stockpiles, with the cost savings from working designs outweighing the cost of bulk solid flow tests.

Unfortunately, flow stoppages and blockages due to arching and ratholing of cohesive materials are common problems in bins and silos. By determining the flow properties of bulks solids and designing materials handling storage facilities based on these flow properties, most flow problems can be prevented.

## 2. BULK MATERIAL TESTING & TYPICAL RESULTS

Good knowledge of the flowability characteristics of bulk materials are essential to successful design, eliminating unnecessary risk and ensuring a smooth transition from the construction to operational phase.

For bulk materials with a significant percentage of particles finer than about 4 mm, the cohesive strength of the bulk material is governed by this fraction.

Before the bulk strength of a sample is established, the sample needs to be prepared. The sample is screened to ensure only the -4 mm fraction is used for bulk solids flow testing. In general the samples can be crushed in the laboratory; it is recommended that samples are screened because crushing can influence the internal and wall friction angles of the material.

The following material flow test work is recommended for design of typical materials handling components such as chutes, bins, silos, stockpiles and conveyors:

- Particle size distribution analysis of the sample
  - Defines the particle size distribution of the bulk material

- Jenike instantaneous tests

The minimum required mass flow openings and hopper angles for instantaneous flow are obtained. The critical rathole diameters for instantaneous flow are determined and used to design funnel flow storage systems.
- Jenike time storage tests

Bulk materials in general gain cohesive strength when exposed to a compressive stress for some time, like in a bin, silo or stockpile. The minimum required mass flow openings and hopper angles for time storage conditions are obtained. The critical rathole diameters for time storage conditions are obtained and are used to design funnel flow storage systems.
- Density and compressibility tests

The bulk density values of the sample are determined as a function of range for a range of consolidation pressures. The bulk density design values varies for conveyor loading, live capacity and feeder load calculations
- Jenike wall friction tests for different types of liners.

The wall friction angles for a specific liner are obtained as a function of normal stresses. The wall friction angles are a required parameter to calculate the minimum openings and hopper angles of mass flow bins.
- Chute friction angle tests for different types of liners

The chute friction angle results are used to calculate the build-up angles of the bulk material in chutes, as well as the material velocities throughout the chute.
- Discrete element modelling (DEM) testing & calibration

A sample of bulk material is tested with a series of scaled tests and a discrete element software package is used to match the test results. The calibrated DEM models can be used to visually design chutes.

Below are typical set of bulk solid flow graphs obtained for Platreef material at 2% moisture content:

Platreef is a platinum group element and base metal enriched mafic/ultramafic layer situated along the base of the northern limb of the Bushveld Complex in the Rustenburg area of South Africa.

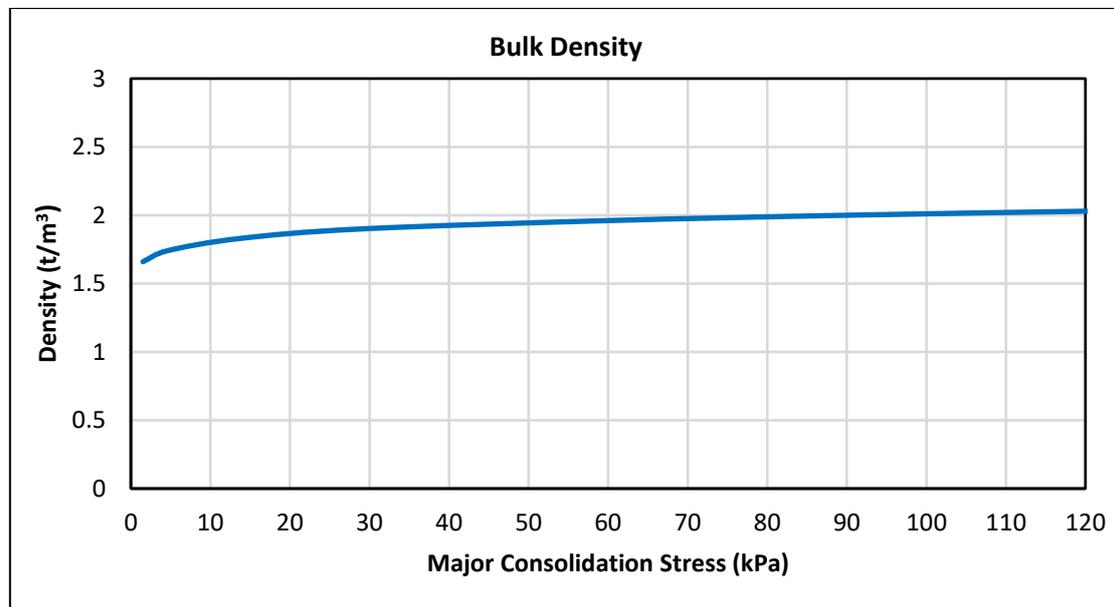


Figure 1. Bulk density results for Platreef material @ 2 % moisture content.

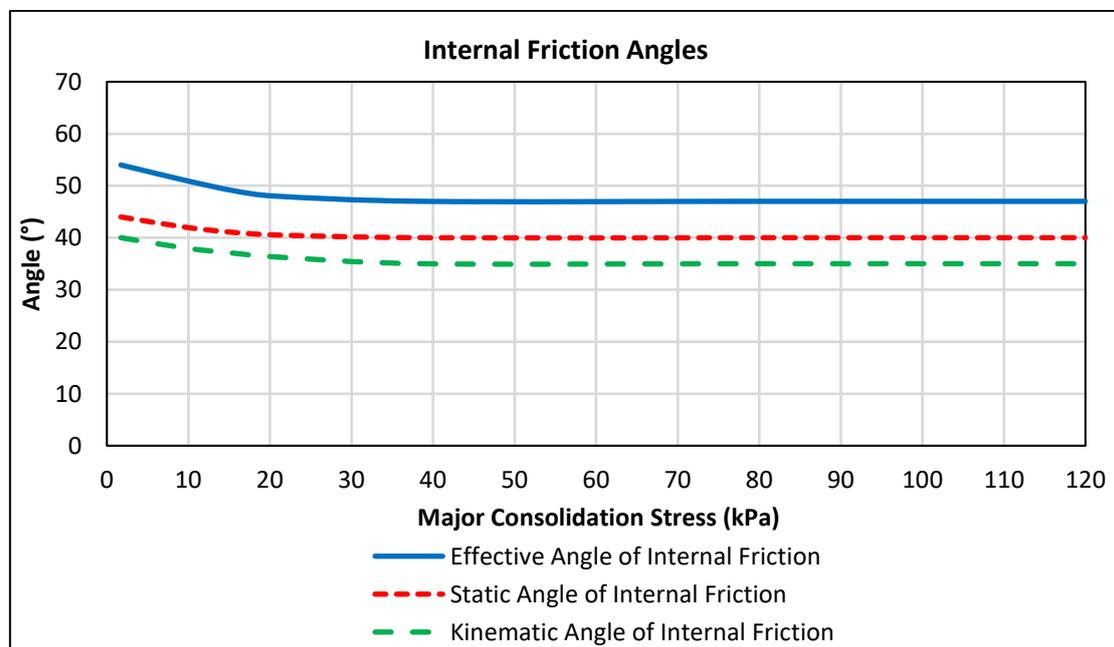


Figure 2. Internal friction angles determined for the Platreef material @ 2% moisture content

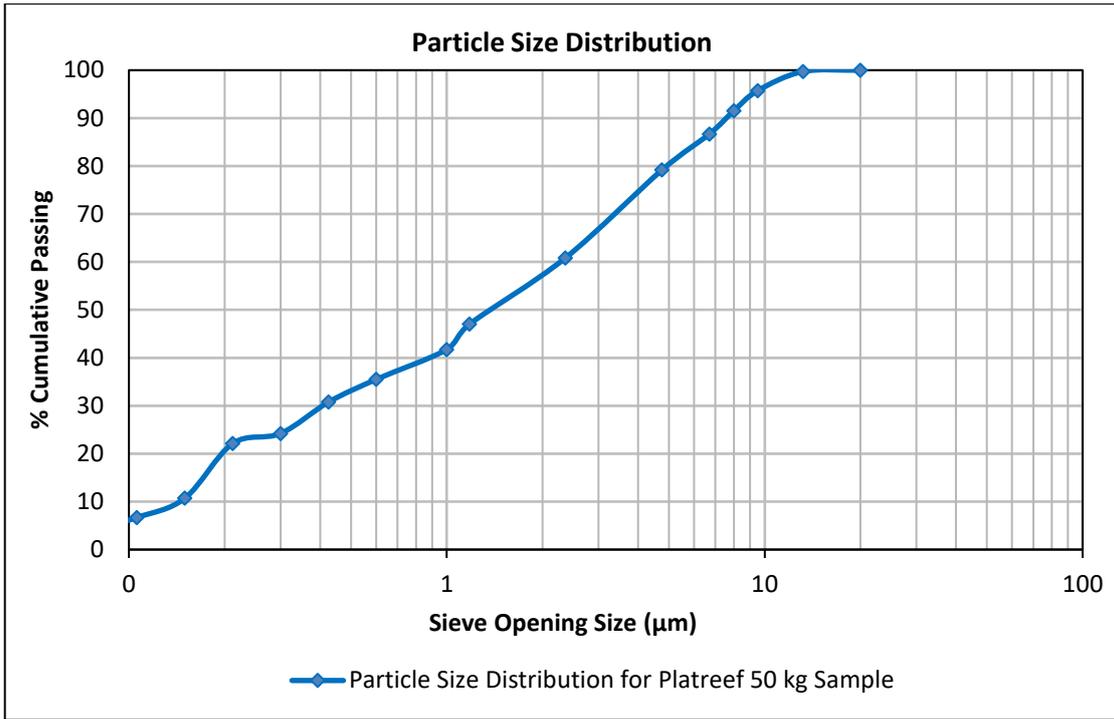


Figure 3. Internal friction angles determined for the Platreef material @ 2% moisture content

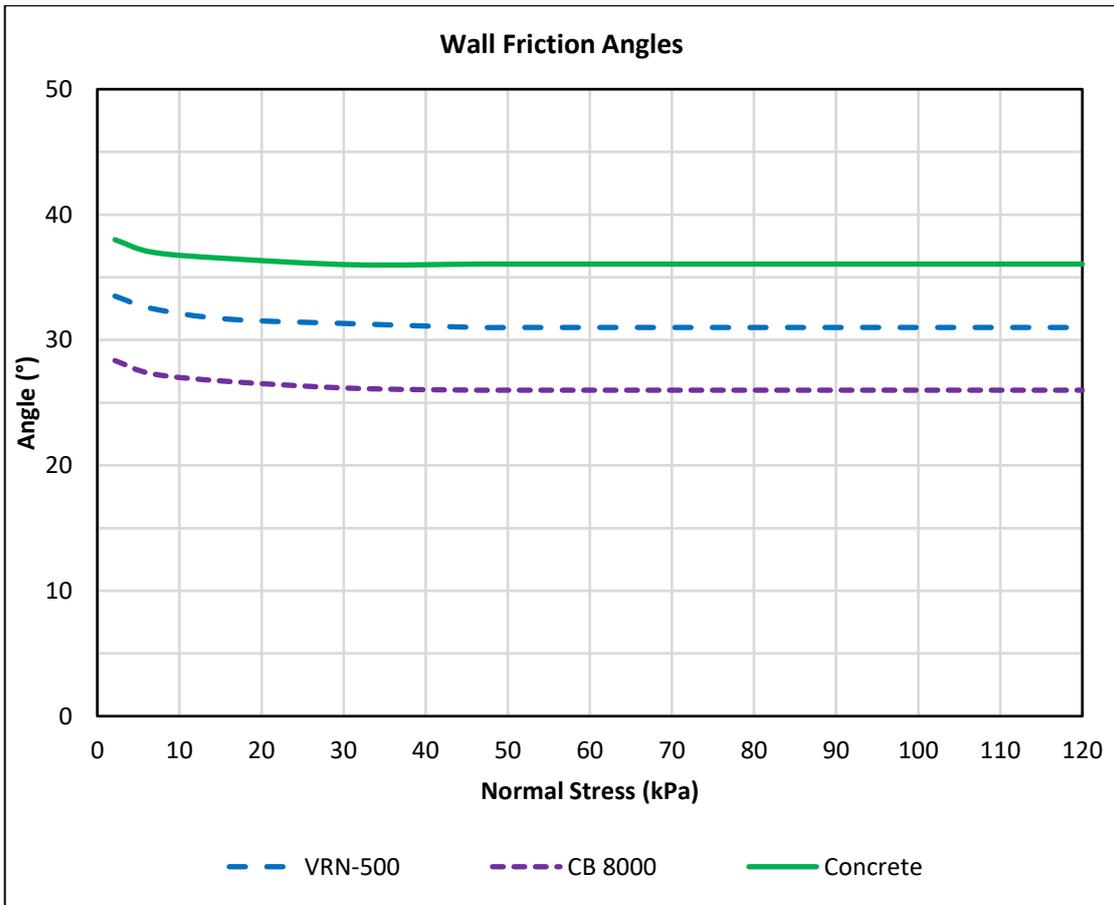


Figure 4. Wall friction angle results per liner, for the Platreef material @ 2% moisture content.

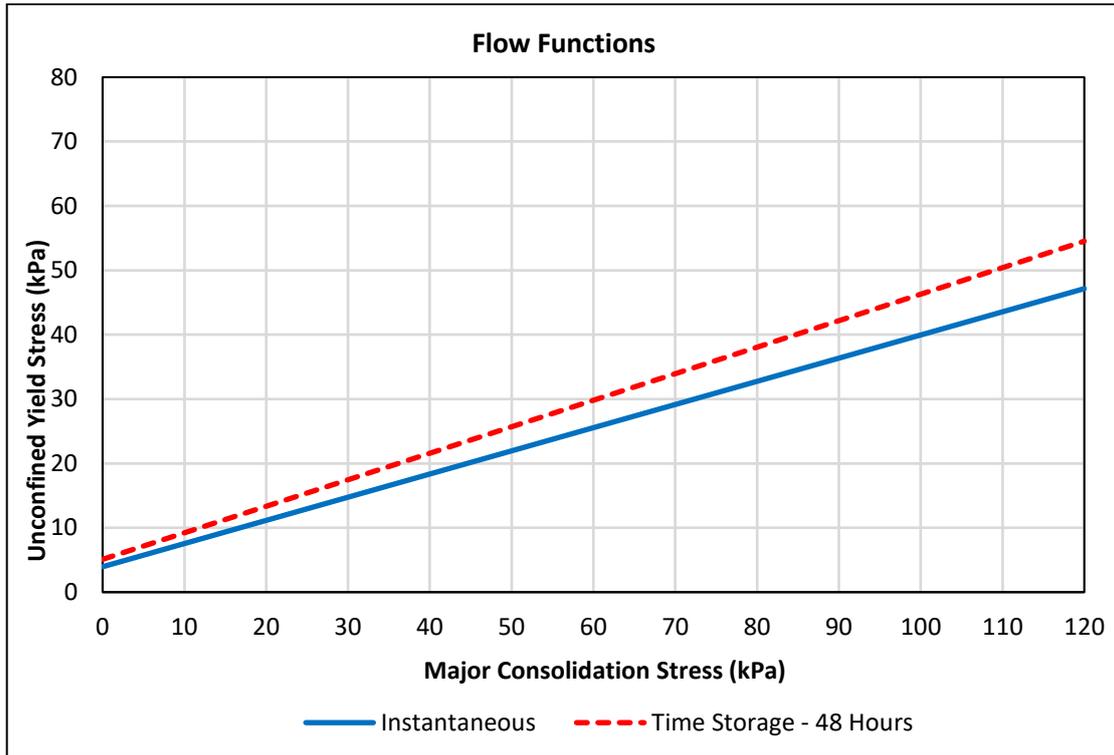


Figure 5. Flow functions obtained with the Jenike shear tester for Platreef material @ 2% moisture content.

From the bulk solid flow graphs design parameters are determined, which are used to materials handling systems.

**MASS FLOW DESIGN PARAMETERS**

For mass flow the bulk solids are in motion at every point within the bin whenever material is drawn from the outlet. Mass flow guarantees complete discharge and the flow rates are predictable. It is a first in first out principle and remixing of the bulk solid can occur during discharge should the solid become segregated upon filling of the bin. The tables below were determined from the bulk solid flow graphs.

Sample	MC	BC (m)	BS (m)	BP (m)	$\Theta_c/\Theta_s$ (°)	$\Theta_p$ (°)	Liner
Platreef	2%	0.909	0.721	0.436	17	24	CB 8000
Platreef	2%	0.856	0.682	0.447	11	18	VRN-500
Platreef	8%	1.145	0.925	0.583	12	19	CB 8000
Platreef	8%	1.082	0.878	0.595	8	14	VRN-500

Table 1. Platreef material @ 2% and 8% moisture contents - Mass flow - Instantaneous minimum requirements.

Sample	MC	BC (m)	BS (m)	BP (m)	$\Theta_c/\Theta_s$ (°)	$\Theta_p$ (°)	Liner
Platreef	2%	1.321	1.012	0.630	17	25	CB 8000
Platreef	2%	1.236	0.954	0.655	11	18	VRN-500
Platreef	8%	1.860	1.430	0.940	17	25	CB 8000
Platreef	8%	1.751	1.357	0.982	10	20	VRN-500

Table 2. Platreef material @ 2% and 8% moisture contents - Mass flow - 48 Hours time storage minimum requirements.

Where

- BC (m) – Minimum diameter of a circular discharge opening for a mass flow bin
- BS (m) – Minimum side of a square discharge opening for a mass flow bin
- BP (m) – Minimum width of a slot discharge opening for a mass flow bin
- $\Theta_c/\Theta_s$  (°) – Maximum angle (with vertical) for a conical/square hopper walls and end walls of a transition hopper for mass flow
- $\Theta_p$  (°) – Maximum angle (with vertical) for a plane flow hopper walls and end walls of a transition hopper for mass flow

#### **FUNNEL FLOW DESIGN PARAMETERS**

Funnel flow works on a first in last out principle and maximum levels of segregation are present. Typical funnel flow storage facilities are stockpiles, flat or tapered bottom bins and silos. Funnel flow storage facilities are prone to form stable piping diameters above feed openings reducing the overall live capacity under gravity flow conditions if designed incorrectly. Flow promotion aids are often required to initiate and maintain flow.

It should be noted for funnel and expanded flow storage facilities that the critical piping diameters below represent the -4mm particle size distribution. For functional design these values can be adjusted or reduced depending on the percentage fines in the incoming stream of material. This will lead to large capital savings during the design phase. There are many different points of views and theories regarding these reductions factors by experts in industry.

Below are the calculated critical rathole diameter results for Platreef material at 2% moisture content.

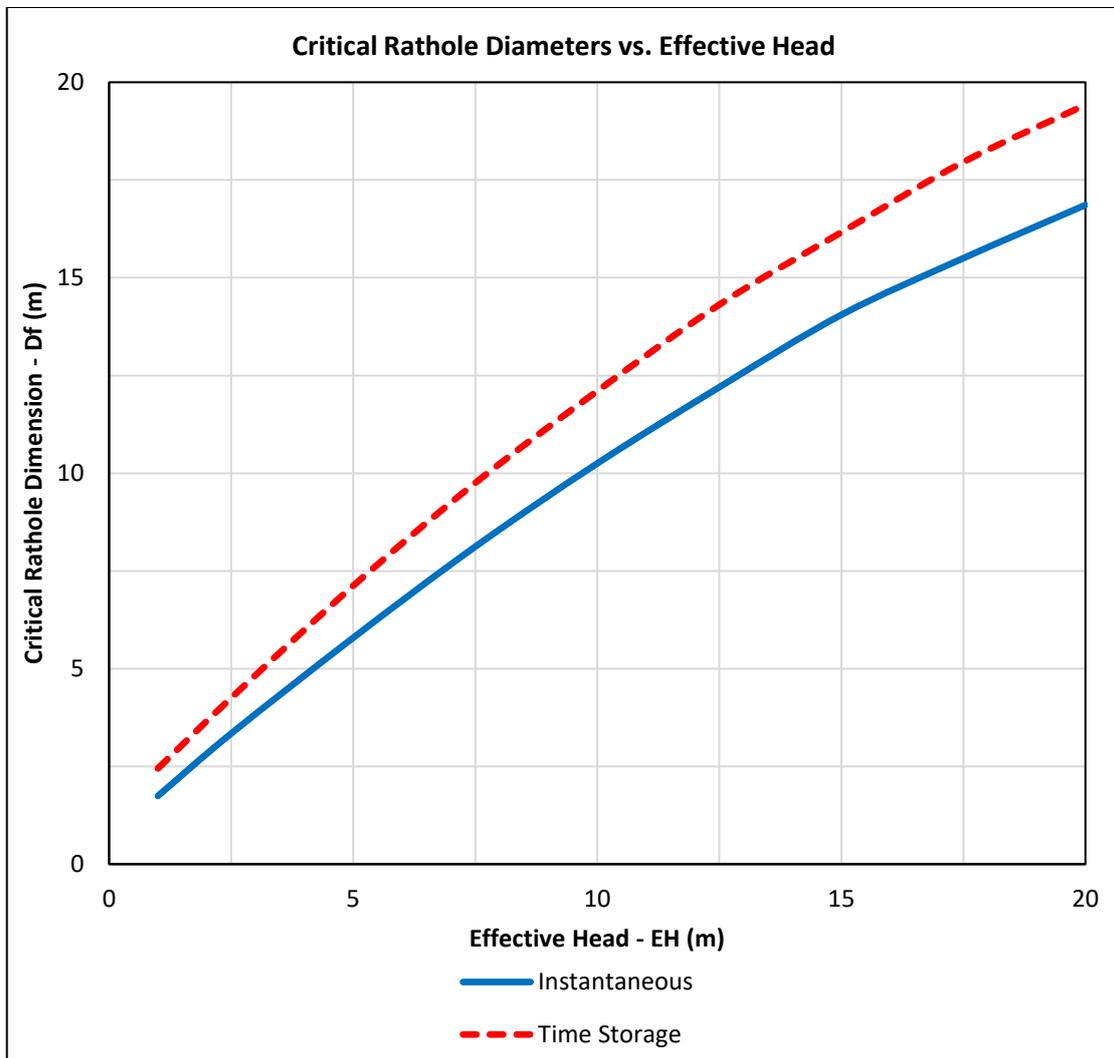


Figure 6. Critical rathole dimensions – Platreef @ 2% moisture content.

<b>Instantaneous</b>	
<b>Df (m)</b>	<b>Effective Head (m)</b>
1.75	N/A
3.34	2.5
5.79	5
8.12	7.5
10.25	10
12.20	12.5
14.05	15
15.50	17.5
16.86	20

Table 3. Tabulated instantaneous critical rathole dimensions – Platreef @ 2% moisture content.

<b>Time Storage - 48 hours</b>	
<b>Df (m)</b>	<b>Effective Head (m)</b>
2.45	N/A
4.25	2.5
7.12	5
9.75	7.5
12.10	10
14.31	12.5
16.16	15
17.96	17.5
19.42	20

Table 4. Tabulated time storage critical rathole dimensions – Platreef @ 2% moisture content.

### 3. DESIGN OF MATERIALS HANDLING STORAGE FACILITIES

The following procedures are required for the design of a materials handling plant consisting of bins, silos, gravity reclaim stockpiles, feeders and transfer chutes:

1. Determination of the strength and flow properties of the bulk solids for the worst case flow conditions most likely to be expected in practice.
2. Determination of the bin, silo, gravity reclaim stockpile, feeders and transfer chute geometry to create a functional design to the correct live capacity and flow pattern requirements.
3. Estimation of the pressures and loadings through bin, silo and stockpile discharge openings, as well as the normal forces on the wall. This is required for feeder power consumption and start-up calculations as well as structural design.

A bin (silo, bunker) generally consists of a vertical cylinder and a sloping, converging hopper. The first step in the process of bin selection is to decide on the type of bin required. There are three types of bins:

1. Mass flow
2. Funnel flow
3. Expanded flow



Figure 7. Photograph of mass flow bin containing Platinum material.



Figure 8. Photograph of funnel flow bin for run of mine Platinum ore.



Figure 9. Photograph of expanded flow flat bottom silo containing Platinum material.



Figure 10. Photograph of expanded flow stockpile containing Platinum material.

#### **MASS FLOW BIN DESIGN**

In a mass flow bin, the hopper is sufficiently steep and smooth to cause flow of all the bulk material without stagnant regions whenever any bulk material is withdrawn. The two important design parameters that define a mass flow bin are the half hopper angle,  $\alpha$ , and the minimum slot width,  $B$ . Mass flow bins, examples of which are shown in Figure 11, have certain advantages. The flow is uniform, and the discharge flow rate is practically independent of the head of solids in the bin. This frequently permits the use of volumetric feeders for feed rate control. Since stagnant regions are eliminated, low level indicators work reliably. Even though the solids may segregate at the point of charge into the bin, segregation of the discharge is minimised by the first in first out flow sequence associated with mass flow. This flow sequence also ensures uniform residence time and de-aeration of fine powders (Roberts, 1991, 1998).

Mass flow bins are recommended when handling cohesive materials, powders and materials that degrade with time, and when segregation needs to be minimised. Ledges and protrusions are not permitted in a mass flow hopper. In addition, the outlet must be fully effective. If the hopper is equipped with a radial door or knife gate, the door-gate must not prevent flow of material along the hopper walls. If a feeder is used, it must draw material across the full outlet area. Mass flow bins can be used for in-bin blending.

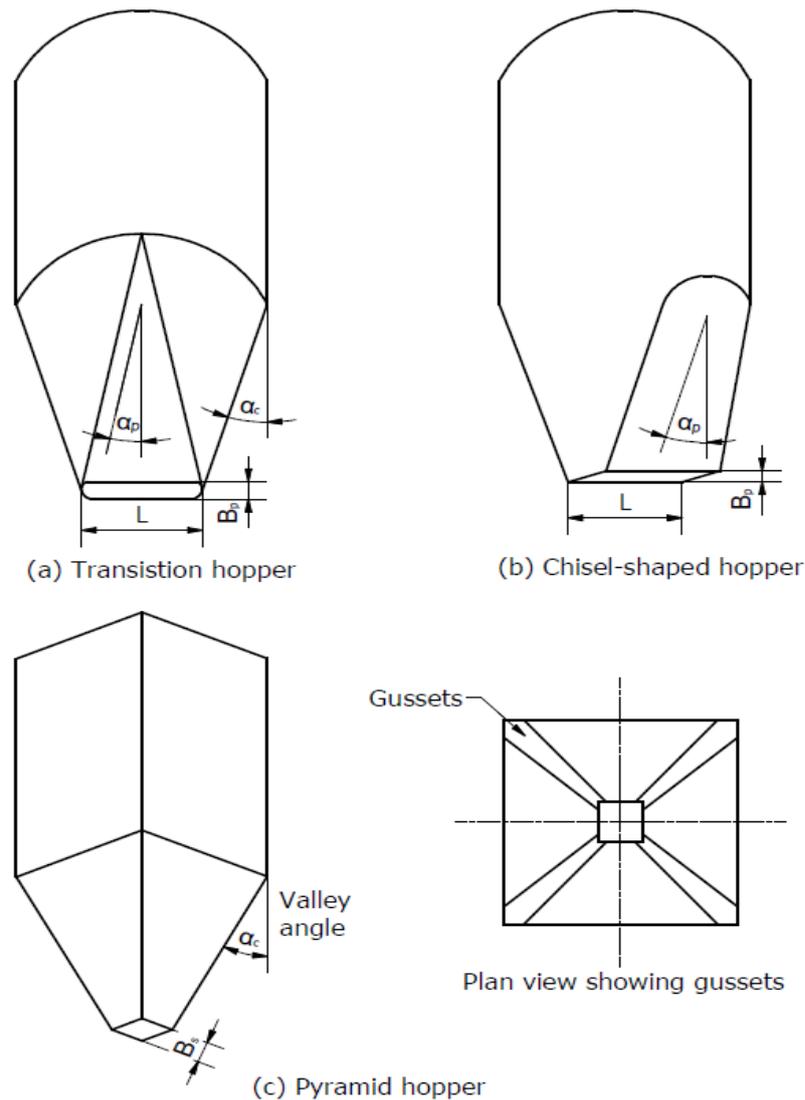


Figure 11. Examples of mass flow bins.

### FUNNEL FLOW BIN DESIGN

Funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls. It also occurs when the outlet of a mass flow bin is not fully effective. Examples of funnel flow bins are shown in Figure 12. The width  $B$  should be sufficient to prevent a stable arch from forming across the opening.

In a funnel flow bin, bulk material flows towards the outlet through a channel that forms within stagnant material. With non-free-flowing solids, this channel expands to a diameter that approximates the largest dimension of the outlet. When the outlet is fully effective, this dimension is the outlet's diameter, for all opening types such as circular or diagonal if the outlet is square or rectangular. The channel will be stable if its diameter is less than the critical rathole diameter. With free-flowing solids, the flow channel expands at an angle that depends on the effective angle of internal friction of the material. The resulting flow channel is generally circular with a diameter in excess of the outlet diameter or diagonal. When the bin discharge rate is greater than the charge rate, the level of solids within the channel drops, causing

layers to slough off the top of the stagnant mass and fall into the channel. This spasmodic behaviour is detrimental with cohesive solids since the falling bulk material packs on impact, thereby increasing the possibility of arching. With sufficient cohesion, sloughing may cease, allowing the channel to empty out completely and form a stable rathole. Aerated solids charged into this empty rathole may overflow the feeder (Roberts, 1991, 1998).

When a fluidised powder is charged directly into a funnel flow channel at a sufficiently high rate and is withdrawn at the same time, it has no opportunity to de-aerate. It therefore remains fluidised in the channel and floods when exiting the bin. A rotary valve is often used under these conditions to contain the material, but a uniform flow rate cannot be ensured because flow into the valve is erratic. In general, funnel flow bins are suitable only for coarse, free-flowing or slightly cohesive, non-degrading solids, when segregation is unimportant.

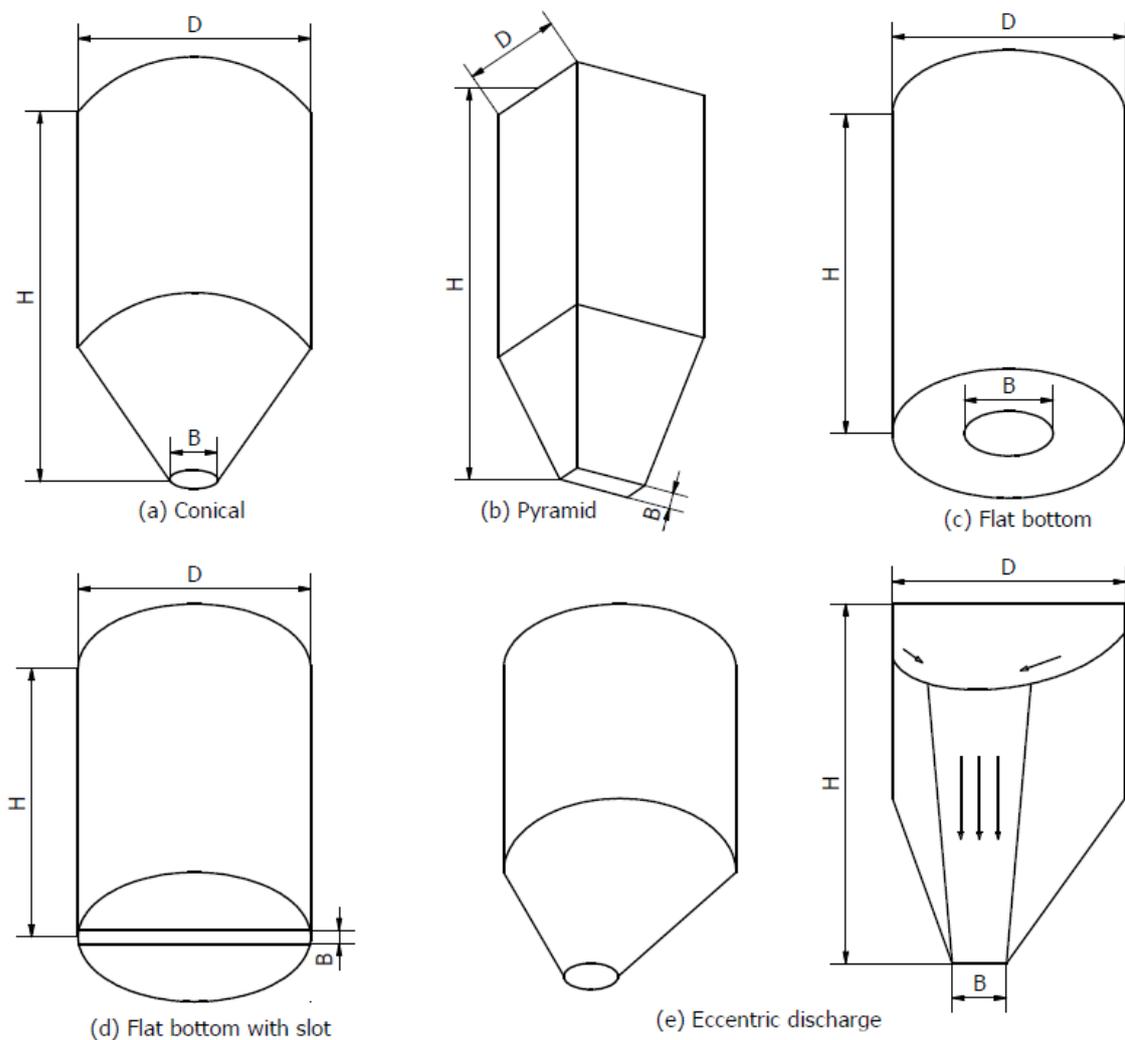


Figure 12. Examples of funnel flow bins.

## EXPANDED FLOW BIN DESIGN

Examples of expanded flow bins are shown in Figure 13. The lower part of such a bin operates with flow along the hopper walls (similar to mass flow), while the upper part operates in funnel flow. The mass flow outlet usually requires a smaller feeder compared to a funnel flow bin. The mass flow hopper section should expand the flow channel to a diagonal or diameter equal to or greater than the critical rathole diameter,  $D_f$ . This eliminates the likelihood of ratholing in the funnel flow section. These bins are used for storage of large quantities of non-degrading solids. This design is also useful as a modification of existing funnel flow bins to correct erratic flow caused by arching, ratholing or flooding. This concept can be used with multiple outlets as shown in Figure 13 (b), where a series of mass flow hoppers are placed close enough together to cause a combined flow channel larger than the critical rathole diameter. With extremely free-flowing solids such as plastic pellets, cement clinker, and coarse sand, both funnel flow and expanded flow bins may pulsate. This is caused by the flow pattern suddenly switching from a steady state, central channel-type flow to a much more extensive secondary flow pattern, which may extend to the bin walls. Such a condition may reduce segregation problems, but the shock loads imposed may seriously challenge the structural integrity of the bin (Roberts, 1991, 1998).

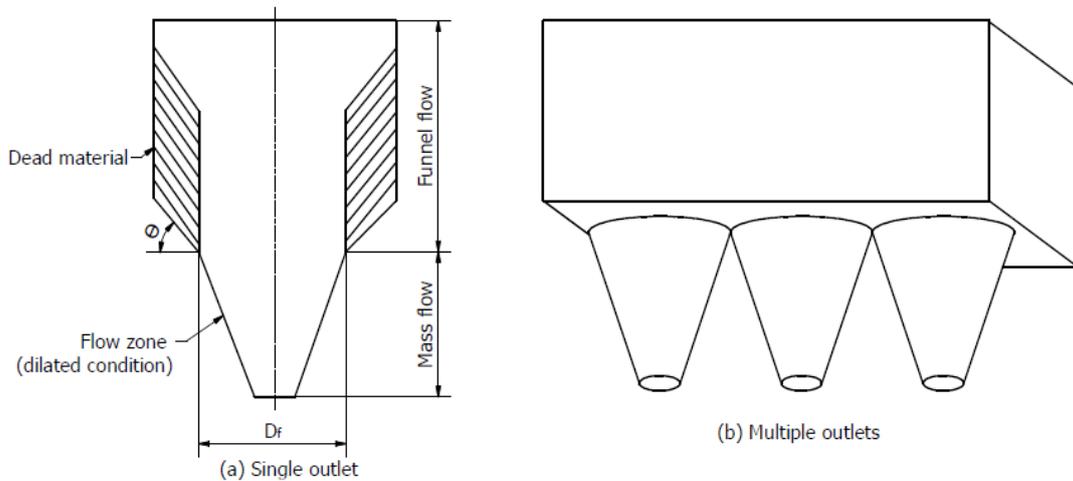


Figure 13. Examples of expanded flow bins

## MASS FLOW AND FUNNEL FLOW LIMITS FOR SYMMETRICAL BINS

Jenike developed the limits for mass and funnel flow assuming a radial stress field exists in the hopper (Jenike, 1961, 1964). The limits for conical and plane-flow hoppers depend on the hopper angle,  $\alpha$ , the effective angle of internal friction,  $\delta_e$ , and the wall friction,  $\phi_w$ . The effective angle of internal friction and wall friction are determined by laboratory tests; once these values are established, the hopper angle may be determined as follows:

$$\alpha = \frac{\pi}{2} - \frac{1}{2} \cos^{-1} \frac{(1 - \sin \delta_e)}{2 \sin \delta_e} - \beta \quad (1)$$

Where

$$\beta = \frac{1}{2} \left[ \phi_w + \sin^{-1} \left( \frac{\sin \phi_w}{\sin \delta_e} \right) \right] \quad (2)$$

For plane-flow hoppers, the discharge is by planar converging motion, and the bounds between mass and funnel flow are much less severe than for conical hoppers where the discharge converges radially inward. Therefore, for conical hoppers, the hopper angle is steeper than that of plane-flow bins. Since the work of Jenike for flow in a hopper is based on the radial stress field theory, the influence of the surcharge head due to the cylinder height of the bin is ignored when a flow pattern is developed (Roberts, 1991, 1998).

The aim in mass flow design is to determine the minimum hopper angle,  $\alpha$ , to ensure flow along the walls, and the minimum hopper opening dimension,  $B$ , to prevent material from arching in the bin. The critical opening dimension,  $B_{cr}$ , is obtained for the condition when the stress in the arch,  $\bar{\sigma}_1$ , equals the unconfined yield strength,  $\sigma_c$ . This point occurs at the intersection point of the flow function, FF, and the flow critical factor, ff.

The following equation was developed by Jenike to determine the critical opening dimension,  $B_{cr}$

$$B_{cr} = \frac{\bar{\sigma}_1 H(\alpha)}{\rho g} \quad (3)$$

The function  $H(\alpha)$  from Jenike and Leser (1963) is an arching thickness parameter and may be represented as follow:

$$H(\alpha) = \left[ \frac{(130+\alpha)}{65} \right]^m \left[ \frac{(200+\alpha)}{200} \right]^{1-m} \quad (4)$$

Where

$m = 0$  for rectangular hoppers,

$m = 0$  for conical hoppers and

$m = 0.9$  for square openings.

#### **MAXIMUM HOPPER ANGLES FOR MASS FLOW**

A bulk material sliding on a bin wall encounters frictional resistance proportional to the tangent of the wall friction angle. This angle generally depends not only on the roughness of the wall but also on the pressure that the bulk material exerts on the wall. For many hard wall surfaces, the friction angle decreases as the bulk material contact pressure increases. This pressure, which varies with its position in the bin, is usually lowest at the outlet. Therefore, the hopper angle required is often dictated by the outlet size selected. The recommended maximum hopper wall angles,  $\alpha_p$  (long slotted openings) and  $\alpha_c$  (conical or square openings), are measured from the vertical plane of the bin (Hui, 2012).

To minimise headroom, consider changing the slope of the hopper wall as a function of position. For example, if a conical hopper is to be designed with an outlet diameter of 1 m and the recommended  $\alpha_c$  is  $10^\circ$  at 1 m diameter and  $20^\circ$  at 2 m and larger diameters, use two conical sections. In the lower section where the diameter varies from 1 m to 2 m, use a hopper angle of  $10^\circ$ . Above the 2 m diameter, use a hopper angle of  $20^\circ$ . This principal is applied into designing hyperbolic bin shapes. Often, both continuous flow and time friction tests are run on a material. If the solid adheres to the wall with time, the time test results will indicate an increase in friction angles. To overcome this time effect, the hopper walls should be made steeper, as recommended; otherwise, flow aids should be used to promote flow.

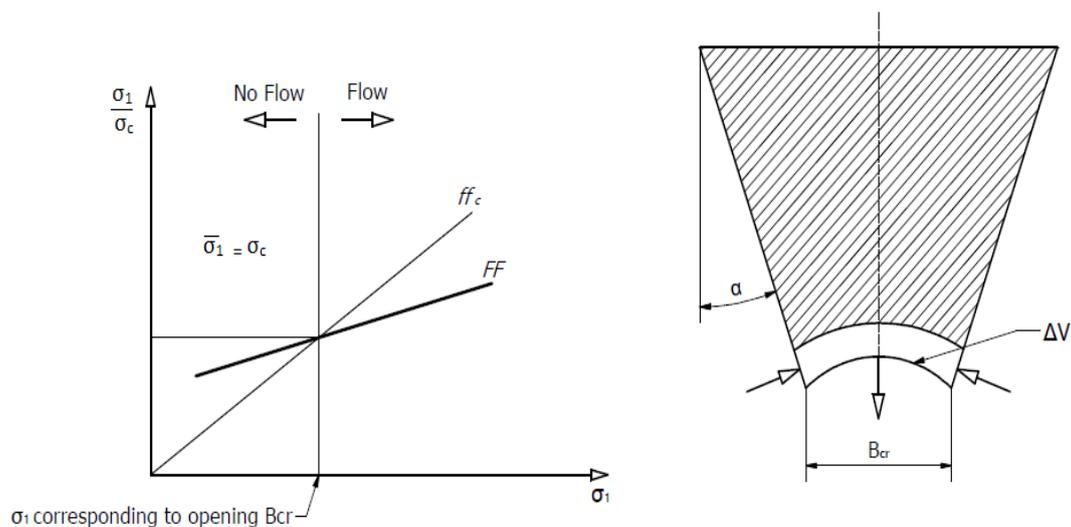


Figure 14. Flow-no flow condition for mass flow design.

#### CALCULATION OF EFFECTIVE HEAD OF A SILO

The critical rathole diameter,  $D_f$ , is a function of the major consolidating pressure that acts on the solids in the bin. It is convenient to express this pressure in terms of  $h_f$ , the effective consolidating head of solid in the bin, as follows:

$$h_f = \frac{R}{\mu K} \left( 1 - e^{-\mu K \frac{h}{R}} \right) \quad (5)$$

Where

R - Hydraulic radius of the cylindrical portion of the bin – ratio of cross sectional area to circumference

R -  $\frac{B}{4}$  for a circular cylinder of diameter B or a square cylinder of side B

$\mu$  - Coefficient of friction between the stored solid and the cylinder walls

K - Ratio of horizontal to vertical solids pressure. A value of 0.4 is usually acceptable within cylinders

#### h - Height of the cylindrical portion of a bin

A less conservative method is to calculate the critical rathole diameter for a bin or silo by determining the flow and initial loads for the channel of effective withdrawal. The initial loads can easily be converted to an effective head and the corresponding critical rathole diameter can be interpolated from the test work results. In general the effective withdrawal for a stockpile or silo is equal to the effective angle of internal friction plus a 10° safety factor for live capacity purposes.

Silos and stockpiles should be emptied on a regular basis to prevent dead material build-up from consolidating and growing in capacity. If this is not achieved the withdrawal angle can reach approximately 45° plus the effective angle of internal friction divided by two. If a stockpile or silo develops a rathole, the withdrawal angle is usually between 0° – 15° with the vertical plane, depending on the cohesiveness of the material. Therefore ratholing can drastically reduce the live capacity of an expanded flow storage facility.

#### **FEEDERS**

Feeders are used to control the rate of material discharge from a bin (hopper, silo and bunker) outlet. They must not be confused with conveyors, which simply transport material from one point to another. Common feeders include screw, belt, apron, rotary plows and vibrating feeders. The rate of material being discharged is most commonly controlled volumetrically from these feeders; therefore, it is also critical to use the correct bulk density from test results to ensure the required flow rate is met. The volume of material per unit time may be varied by changing the feeder speed, amplitude or frequency or the front opening area of discharge. Several of these feeders may also operate gravimetrically and the mass of material per unit time is measured and controlled. Proper feeder selection depends on a number of factors based on the bin choice and feed requirements. Two major objectives for efficient feeder design are uniform withdrawal of the material from the entire bin outlet area and minimising the material loads on the feeder, all within the process requirements of flow rate and layout. In order to ensure that the outlet is fully effective, the choice of feeder must be based on the outlet size and shape. If the requirements of bin selection dictate that the outlet be slotted, the feeder must increase in capacity in the direction of feed to ensure a uniform draw of material across the entire outlet. The choice of feeders is generally limited to a belt, apron or a vibrating feeder in the mining industry (Hui, 2012).

If the feeder's capacity does not increase correctly, the feeder will tend to draw material from either the front or back of the opening of the bin, resulting in a high velocity flow channel having a diameter only one to two times the width of the slot. This becomes critical when feeding powders, since the powder may remain fluidised within this channel and flood on exiting the bin.

Feeders should also be designed to have sufficient torque to break away initial shear forces and have sufficient installed power to operate at running conditions.



Figure 15. Photograph of a vibrating feeder at the bottom of a bin



Figure 16. Photograph of a belt feeder at the bottom of a stockpile



Figure 17. Photograph of an apron feeder

#### **4. CASE STUDY – UG2 STOCKPILE WITH MASS FLOW AND RATHOLING PROBLEMS DUE TO AN INCREASE OF THE FINES PERCENTAGE & MATERIAL'S MOISTURE CONTENT**

A platinum mine was operating an existing stockpile approximately 12 m high with UG2 material at 5% moisture content material. The stockpile was fed with an incoming conveyor and the bulk stream feeding the stockpile contained a -4mm fraction percentage between 25% - 30%. The stockpile was reclaimed by gravity flow with two vibrating feeders (expanded flow). The stockpile did not experience any problems such as ratholing and arching of material in the mass flow chutes. Eventually the stockpile faced a changeover of material and new underground UG2 material at 10% moisture content was stockpiled. The new material contained a higher percentage -4mm fraction that ranged between 35% - 40%. With the new UG2 material at 10% moisture content the stockpile experienced regular problems. The mass flow chutes blocked frequently affecting production output and the stockpile's live capacity was reduced due to ratholing. A site investigation was conducted and the aim was to determine solutions with minimum downtime for handling a more cohesive UG2 material than what was originally designed for.

Bulk material flow testing was conducted for instantaneous and time storage conditions by means of Jenike shear testing and the results were evaluated and used to evaluate the stockpile. For this paper only the mass flow parameters are considered.

Sample	MC	BC (m)	BS (m)	BP (m)	$\Theta_c/\Theta_s$ (°)	$\Theta_p$ (°)	Liner	Storage
UG2 Ore	5%	0.600	0.560	0.300	13	23	VRN-500	0 Hrs
UG2 Ore	5%	0.760	0.690	0.380	14	24	VRN-500	48 Hrs
UG2 Ore	10%	0.890	0.780	0.470	14	24	VRN-500	0 Hrs
UG2 Ore	10%	1.180	1.050	0.570	16	26	VRN-500	48 Hrs

Table 1. Run of mine UG2 material @ 5% and 10% moisture contents - Mass flow – Instantaneous & Time storage requirements.

The following factors and risks were considered:

- Arching problems
- Live capacity
- Downtime during installation of proposed solutions
- Possible improvements and modifications
- Cost
- Bulk materials testing and flowability

#### STOCKPILE PROPERTIES

The following material and stockpile properties were used in conjunction with the mass flow test work results:

- |  |                        |
|--|------------------------|
| ▪ Material                                     | UG2                    |
| ▪ Required Live Capacity                       | 2000 tons              |
| ▪ Expected Moisture Content                    | 5% - 10%               |
| ▪ Maximum lump size                            | 300 mm x 500 mm        |
| ▪ Maximum Diagonal Lump                        | 583 mm                 |
| ▪ Minimum Material Density @ 0 kPa (Discharge) | 2000 kg/m <sup>3</sup> |
| ▪ Minimum Material Density @ 60 kPa (Volume)   | 2200 kg/m <sup>3</sup> |
| ▪ Minimum Material Density @ 120 kPa (Load)    | 2400 kg/m <sup>3</sup> |

The material properties and design parameters obtained from test work for the 5% and 10% moisture content material were compared. This was used to predict the difference in flowability of the UG2 ore. It was evident that the 10% moisture content material was more cohesive.

The existing mass flow chute properties onto vibrating feeders were as follows:

- Square opening width = ± 900 mm
- Hopper angle with the vertical for VRN-500 = 14°

Since material could be stored for periods longer than 48 hours, the mass flow design parameters for time storage conditions were selected. For UG2 ore at 5%

moisture content the following design parameters are important to achieve mass flow:

- Minimum square opening width required = 690 mm
- Minimum hopper angle required with the vertical for VRN-500 = 14°
- Angle of repose = 34° - 36°

The stockpile with mass flow chute interfaces feeding onto vibrating feeders worked sufficiently and no arching occurred for 5% moisture content UG2 material. All the design parameters adhered to the test work results.



Figure 18. Existing stockpile - Underground ore - Angle of repose = 34° for 5% moisture content

The mass flow requirements for UG2 ore at 10% moisture content and 48 hour time storage conditions were as follow:

- Minimum square opening width required = 1 180 mm
- Minimum hopper angle required with the vertical for VRN-500 = 16°
- Angle of repose = 40° - 45°



Figure 19. Temporary Stockpile - Underground Ore - Angle of Repose = 45° for 10% Moisture Content

## 5. CONCLUSION

From the test results it was concluded that there are large variations between the flowability of the 5% and 10% moisture content material. The stockpile with 5% moisture content material worked sufficiently and had sufficient operational live capacity. Once the stockpile was in operation with 10% moisture content material, the stockpile withdrawal tended to rathole and the mass flow chutes blocked frequently. The existing mass flow chutes with openings of 900 mm wide did not adhere to the requirements of the test results which specified square opening widths of 1180 mm. The hopper angles were not affected according to the test work, but the VRN liners inside the chute were corroded affecting the wall friction. A functional design was done to predict the ratholing effects and the modifications required for the mass flow chutes.

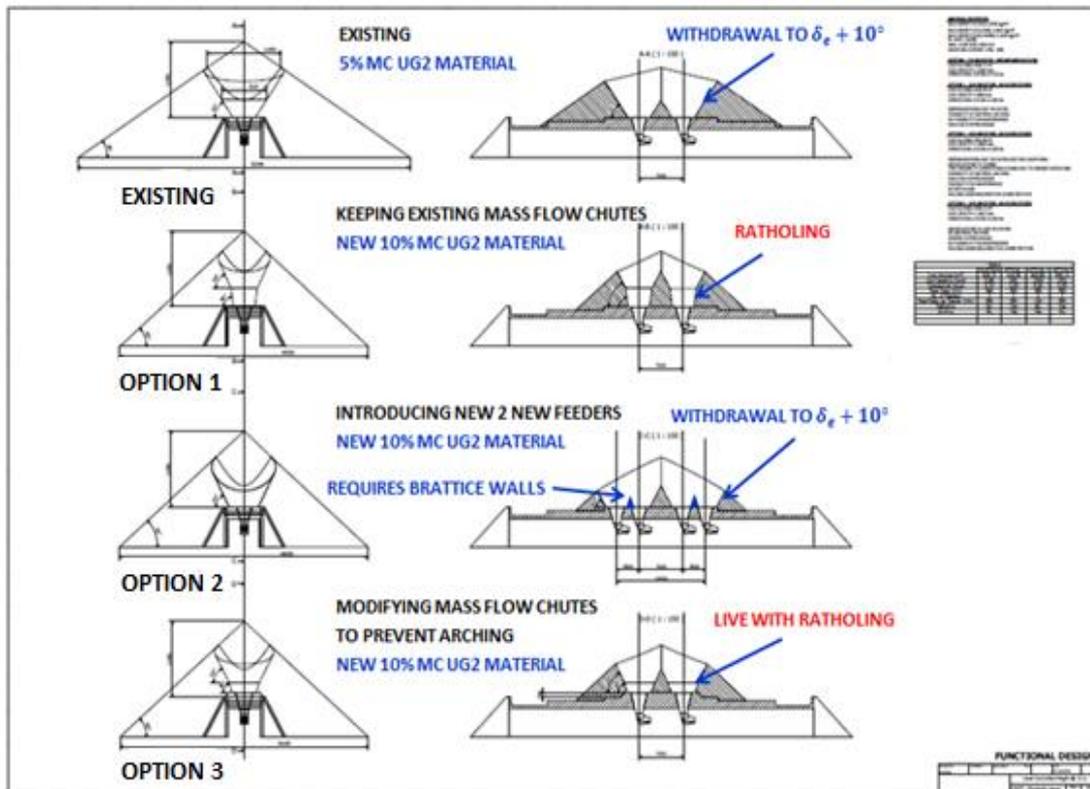
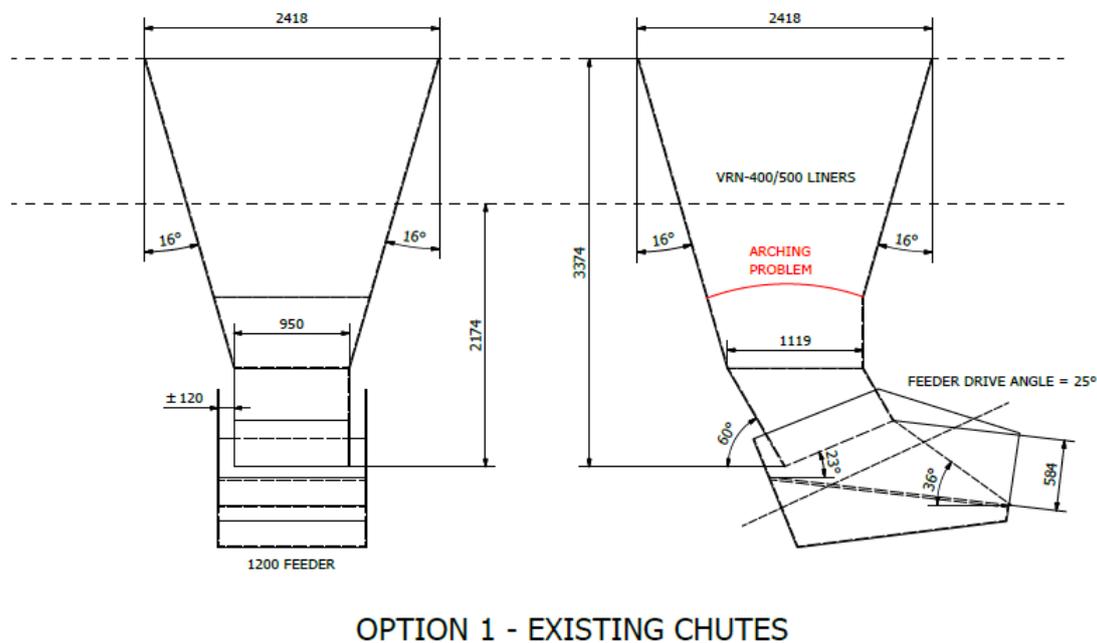


Figure 20. Stockpile functional design comparisons for different options

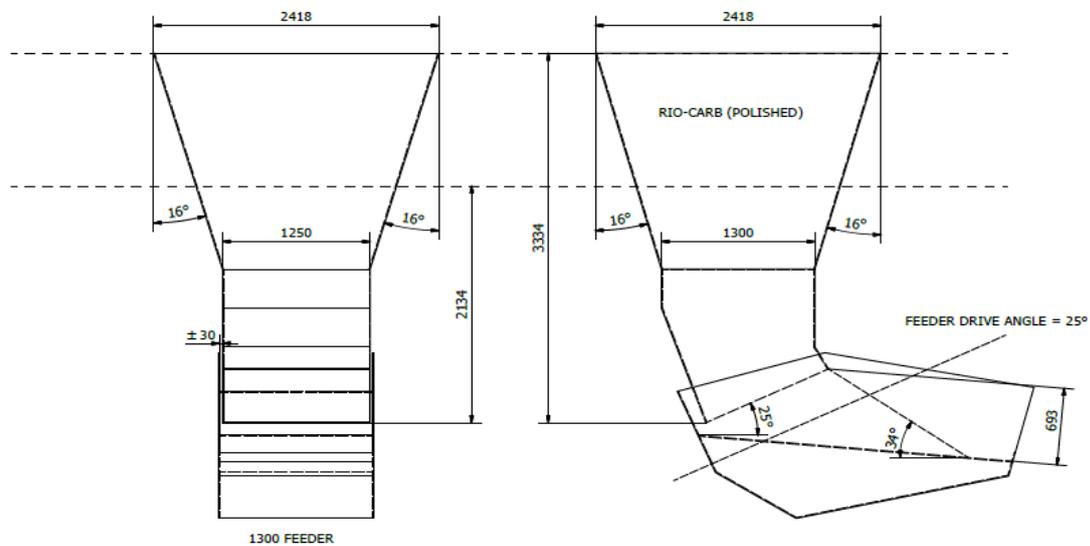


OPTION 1 - EXISTING CHUTES

Figure 21. Option 1 - Existing mass flow chutes and feeder interface

The existing mass flow chute in Figure 21 created arching problems for UG2 material at 10% moisture content, although it worked for 5% material. The diagonal length of the top opening of the mass flow chute also didn't meet critical rathole requirements that were obtained from the testwork results. This caused a decrease in operational

live capacity due to ratholing. It was also established that the arching dimensions (indicated in red) is not far above the actual opening.



### OPTION 2 - WIDER FEEDERS, IMPROVED CHUTES

Figure 22. Improved mass flow chutes with wider feeders

The problem with implementing a new design, there was many constraints such as tunnel height and downtime to implement the designs. Therefore it was decided to look at solutions improving the design, considering the availability of height. This did not formulate a rigid solution as compared to what could have been achieved in the initial phases of design before construction. The stockpile tunnel height couldn't have been adjusted to fit all the mass flow requirements.

The improved mass flow chute in Figure 22 adheres to the test work parameters and should eliminate the arching problems for UG2 material at 10% moisture content, although the minimum arching dimension selected was border line and still at risk. The diagonal length of the top opening of the mass flow chute didn't meet critical rathole requirements, and live capacity would be lost due to ratholing. To eliminate the ratholing problem an additional two feeder openings were required, with brattice walls. This would stretch the effective diagonal from one mass flow chute to two mass flow chutes combined (in plan-view), meeting required ratholing conditions. Note both feeders should operate simultaneously or in calculated steps. Another improvement was smooth polished Rio-carb liners.

Option	Height (mm)	Live Volume (m <sup>3</sup> )	Live Capacity (tons)	No. of Feeders	Operational Time (hrs)	Material Moisture (%)	Stored Time (hrs)
Existing	11591	908.71	2180	2	5.74	5	48
1	11591	416.55	999	2	2.63	10	48
2	11591	805.89	1934	4	5.08	10	48
3	11591	559.12	1341	2	3.53	10	48

Table 5: Comparison between design pptions – Stockpile height @ 12 m (Level Controlled)



Figure 21. Discharge mass flow chutes with visible hammer rash to promote flow for 10% moisture content material.

The decision by the Client was that an estimated live capacity of  $\pm 3$  hours would be acceptable, therefore accepting ratholing. Changing the stockpile tunnel by adding two additional feeders would create downtime and affect the operation, therefore was discarded. Although no modifications were made to the mass flow chutes as well, this was require to eliminate the arching problems, it should be highlighted how the effect of moisture combined with fines could increase the material's cohesive strength and create flowability problems. Therefore it is critical to establish design parameters for materials handling design by means of testwork.

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Stephan Roos obtained his BSc Mechanical Engineering Degree at the University of Johannesburg. He also furthered his studies and did a Master Degree in Material Flow Testwork at Civil Engineering Department of the University of Johannesburg. He is currently aiming for his Ph.D in the field of Material Flow Testwork and also practises as a ECSA Professional Engineer. He started his career as a design engineer at TWP Projects for a period of 3.5 years and then moved to DRA Projects as a Materials Handling Design Engineer for a period of 4 years. He currently acts as the owner and a Bulk solids flow Consultant for Greentechnical who specialises in material flow testwork technologies and materials handling design. He also does mechanical & structural design for his 2<sup>nd</sup> company Emerge Consulting. He currently works in an association ship with industry leader Wouter Deijis.

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