

LUMPED MASS CONTINUUM MODELLING OF CHAMFERED TRANSFER CHUTES

Paul J. Munzenberger¹, Alan W. Roberts² and Craig A. Wheeler³

¹Aspec Engineering Pty. Ltd.

²TUNRA Bulk Solids.

³The University of Newcastle, Australia.

Modern transfer chute designs nearly always include chamfers for their ability to reduce wear in transfer chute corners. In a transfer chute design process that uses discrete element modelling, chamfers will be included in the model and the final transfer chute design will be predicted to work effectively with them. Typically, due to the time costs associated with discrete element modelling simulations, only a nominal chamfer will be analysed, and the possibility of a better chamfer design will be ignored. In this paper the effect of transfer chute chamfer designs will be investigated by developing equations for equivalent friction that can be substituted into lumped mass continuum models of transfer chutes for fast analysis of chamfered designs.

1 INTRODUCTION

Conveyor transfer chutes are an integral component in a material handling system. Transfer chutes typically move bulk material from one conveyor – the discharge conveyor – to another conveyor – the receiving conveyor, but they can also transfer material to other processes or storage systems. As with every component in a material handling system, the performance of the transfer chutes is critical to the system's efficient operation. The success of a transfer chute is not only based on bulk material property information but also on knowledge of transfer chute design elements. Knowledge of how curved and straight geometry effects transfer chute performance is understood, however, the effect of the cross-section shape on transfer chute performance is less well known. Examples of transfer chute chamfers are shown in Figure 1 where chamfered hood and spoon sections of the same transfer chute are shown.

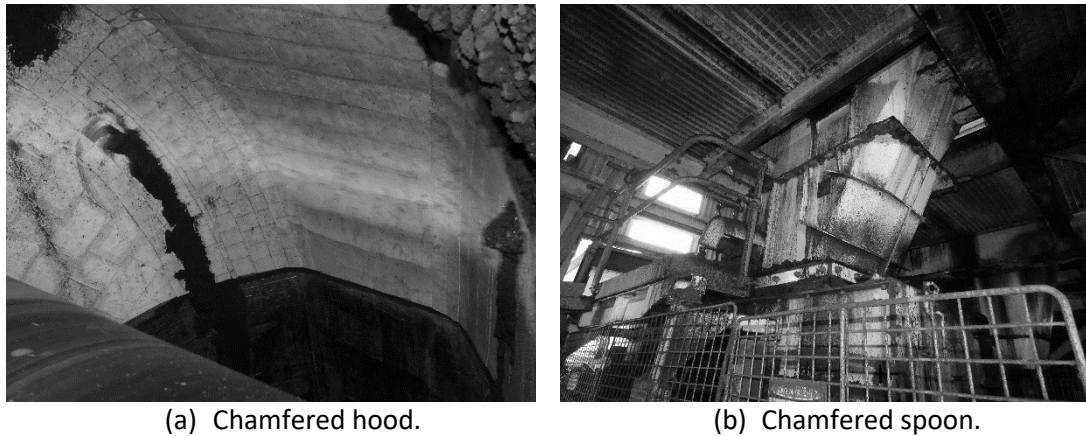


Figure 1. Chamfered transfer chute sections.

Despite the added complexity of their construction, especially on curved surfaces, chamfers are included in transfer chute designs for several reasons. Their main use is to reduce wear in the corners of the transfer chute. This is a result of the lateral pressure applied to a corner particle being directed at a sloped surface instead of a perpendicular surface. Chamfers allow the discharge section of the transfer chute to conform closely to the receiving conveyor's trough shape and are also used when there is a change in transfer chute direction where an upper section needs to morph into a lower section.

Although the effect of chamfers on transfer chute flow performance is not well known, transfer chutes are not usually built without an analysis being conducted on their performance, albeit indirectly. Transfer chute design processes will include a discrete element method (DEM) simulation which will include chamfers in the virtual model if they are included in the design. The DEM simulation will progress with chamfers included, and while adjustments to the curves and slopes of the transfer chute model might be made until a suitable design is found, typically, little effort will be made to vary the chamfer design beyond the original nominal design.

The effect of transfer chute cross-section shape on material flow has been discussed previously. The work of Roberts (Roberts, 2003) is a good example; however, only rectangular and circular transfer chute cross sections are considered. The main transfer chute cross section feature that is missing is the chamfer. Chamfers are a typical feature of modern transfer chute design which means it is important that their effects on bulk material flows is better understood.

In this paper an equation for the equivalent friction of a chamfered transfer chute cross section will be developed. This equation will allow transfer chute designers to quickly assess the effects of rectangular and chamfered transfer chute cross sections using lumped mass continuum modelling (continuum modelling) so that better results can be generated from the subsequent DEM simulations with a reduced number of expensive iterations.

2 CHAMFERED TRANSFER CHUTES

Chamfered transfer chutes are based on transfer chutes with a square cornered cross-section, but on the side where the bulk material flows, the 90° corners are removed and replaced with angled surfaces as in Figure 2(a). These angled surfaces are the chamfers. The angle shown in Figure 2(a) is 45° but it can be any angle. Variations on the chamfered transfer chute that are in use are shown in Figures 2(b) and 2(c).

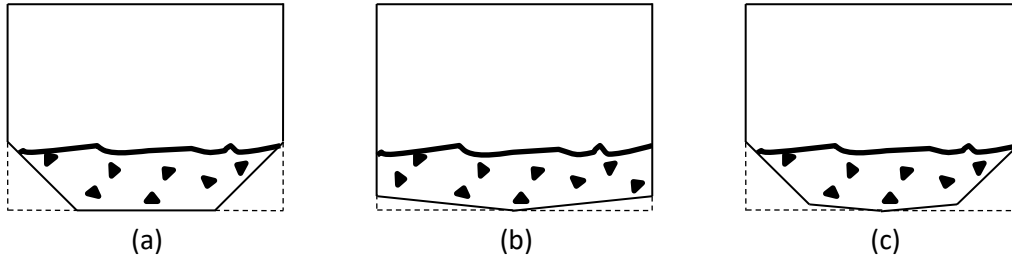


Figure 2. Examples of chamfered transfer chute sections.

The following will focus on the development of equations for the analysis of chamfered transfer chutes like the one shown in Figure 2(a). The equations will allow the analysis of chamfers with the following assumptions:

- The flow is only in contact with the transfer chute chamfers and centre sections.
- The flow area and transfer chute cross-section are symmetrical.
- The free surface of the flow area is parallel with the centre section of the transfer chute.

The equations can be used to analyse 'vee' shaped transfer chutes by setting the length of the transfer chute centre section to zero while bearing in mind the assumption that the flow depth doesn't reach the parallel sides of the cross section. If the flow reaches the parallel sides of the cross-section, the accuracy of the analysis will diminish, and it is up to the designer to determine if sufficient accuracy is maintained at the calculated flow depth. With extensions to the theory, the analysis of different transfer chute cross-sections is possible, however, the calculations become complicated. If the back of the transfer chute section is a shallow 'vee' shape such as in Figure 2(b), or the chamfers are small then it may be reasonable to proceed as if the transfer chute had a square cornered cross-section.

3 EQUIVALENT FRICTION FOR SQUARE CORNERED TRANSFER CHUTES

Roberts (Roberts 2003) gives Equation 1 as the equation of motion for bulk material in the curved spoon section of a transfer chute. This equation is the same for square cornered and chamfered transfer chute spoons. The change in the calculations between the square cornered and chamfered transfer chutes is brought about by changing the way that the equivalent friction, μ_e , is calculated.

$$\frac{dv}{ds} + \mu_e \frac{v}{R} - \frac{g}{v} (\cos \theta - \mu_e \sin \theta) = 0 \quad 1$$

For a square cornered transfer chute section Roberts gives Equation 2 for the equivalent friction.

$$\mu_e = \mu \left[1 + K_v \frac{H}{B} \right] \quad 2$$

When using Equation 1, the equivalent friction is usually calculated with Equation 3 which calculates the current flow depth in terms of the current flow velocity. In this analysis, C is the wetted length of the chamfer and it is equivalent to H when $\beta = 90^\circ$.

$$\mu_e = \mu \left[1 + K_v \frac{C}{B} \right] \quad 3$$

Where $C = \frac{H_0 v_0}{v}$

For square cornered transfer chutes, Roberts recommends a pressure ratio, K_v , of between 0.4 and 0.6. However, for chamfered transfer chutes, this ratio varies with the angle of the chamfer and, as such, an equation is required to derive appropriate ratios.

4 PRESSURE RATIO

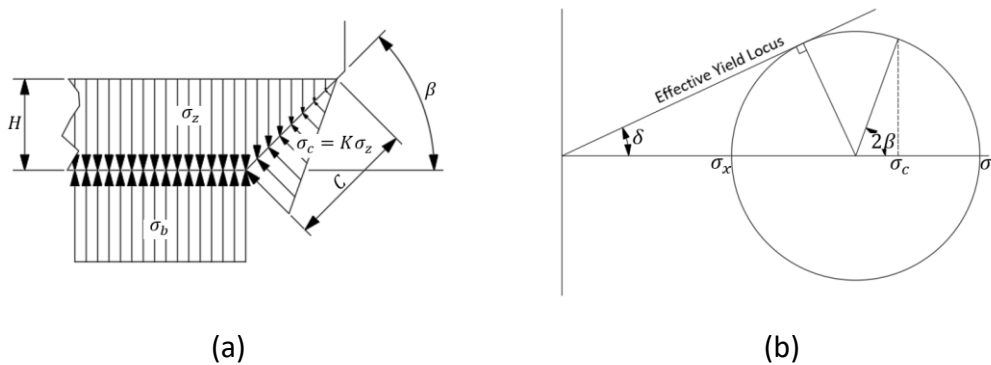


Figure 3. (a) A diagram of transfer chute wall pressure. (b) Mohr's circle for the derivation of the pressure ratio.

As with square cornered transfer chutes, the pressure ratio, K , for a chamfered cross-section must be calculated. Referring to the transfer chute wall pressure and Mohr's circle diagrams in Figure 3, Equation 4 may be derived to calculate the pressure ratio as a function of the chamfer angle, β , and the internal angle of friction of the bulk material δ .

$$K = \frac{\sigma_c}{\sigma_z} = \frac{1 + \sin \delta \cos 2\beta}{1 + \sin \delta} \quad 4$$

Where $0 \leq \beta \leq 90$

Equation 4 may be used to calculate K_v by substituting $\beta = 90^\circ$.

5 EQUIVALENT FRICTION FOR CHAMFERED TRANSFER CHUTES

The calculation of the equivalent friction for chamfered transfer chutes begins, as with square cornered transfer chutes, by assuming hydrostatic conditions prevail. The total

normal load, N_t , is determined by summing the individual normal loads on the centre section, N_b , and each chamfer, N_c , as per Equation 5.

$$N_t = N_b + 2N_c \quad 5$$

$$\text{Where } N_b = \rho g B C \sin \beta \text{ and } N_c = \frac{1}{2} \rho g K C^2 \sin \beta$$

Unfortunately, while Equation 5 is sufficient for square cornered transfer chutes, it is not so for chamfered transfer chutes. This is because the assumption of hydrostatic conditions is not adequate due to the shear resistance within the bulk material. The result of this is that the mass of bulk material resting on the chamfer slope will increase the load on the centre section of the transfer chute and there is an additional reaction which increases the load on the chamfer. Calculation of these additional loads is not trivial and given that they account for less than about ten percent of the total bulk material mass, simplified calculations may be used to determine their magnitudes without a significant loss of accuracy. Here, the missing vertical load, N_m , will be calculated and added to the other normal loads to calculate N_T as per Equation 6.

$$N_t = N_b + 2N_c + N_m \quad 6$$

$$\text{Where } N_m = \rho g (A - B C \sin \beta - K C^2 \sin \beta \cos \beta)$$

Calculation of the equivalent friction for a chamfered transfer chute concludes by first noting that the area of the flow is calculated as per Equation 7 and that the normal load for the continuum model is calculated as per Equation 8.

$$A = (B + C \cos \beta) C \sin \beta \quad 7$$

$$N = \rho g A \quad 8$$

Then making the appropriate substitutions into Equation 9,

$$F = N \mu \left(\frac{N_t}{N} \right) \quad 9$$

Dividing by N as per Equation 10,

$$\mu_e = \frac{F}{N} = \mu \left(\frac{N_t}{N} \right) \quad 10$$

And simplifying,

$$\mu_e = \mu \left(\frac{B + K C + (1 - K) C \cos \beta}{B + C \cos \beta} \right) \quad 11$$

$$\text{Where } 0 \leq \beta \leq 90, C = \frac{-b + \sqrt{b^2 + 4c/v}}{2}, b = \frac{B}{\cos \beta} \text{ and } c = v_0 C_0 (b + C_0)$$

If C is known, Equation 11 may be used directly to calculate the equivalent friction for a chamfered transfer chute. In a dynamic analysis of the flow in a chamfered transfer chute, where the flow velocity is continually changing, the substitution for C must be made.

As expected, Equation 11 will always calculate μ_e to be greater than μ , provided that the range of β is not exceeded, because $\cos \beta \leq 1$. In theory, β can hold any value from 0° – a flat plane, to 90° – a square cornered transfer chute. Thus, Equation 11

should give the same equivalent friction as would be calculated for a flat plane and a square cornered transfer chute. When $\beta = 0^\circ$, K becomes 1 and the bracketed fraction simplifies to 1. When $\beta = 90^\circ$, the cos terms become zero and the equation simplifies to Equation 2. Thus, Equation 11 is a generalised version of Equation 2. Note that when including the substitution equation for C , a value close to 90° should be used so that the coefficient b can be calculated.

6 EQUIVALENT FRICTION FOR VARYING TRANSFER CHUTE CROSS-SECTIONS

Before commencing a transfer chute design project that includes chamfers it is useful to have an idea on how the chamfers will affect transfer chute friction. Three variations will be considered:

- Adjusting the chamfer angle while keeping the centre section length constant.
- Adjusting the chamfer angle while keeping the total width constant.
- Adjusting the chamfer angle while the bulk material height is kept constant.

The analysis of equivalent friction will include a single wall friction angle of 25° and six bulk materials with angles of internal friction ranging from 30° to 55° . The lower end of the range of angles of internal friction is limited by the wall friction value. For a bulk material it can be shown that the maximum attainable wall friction angle, ϕ_s , is equal to $\tan^{-1}(\sin \delta)$. For an internal angle of friction of 30° , the maximum wall friction angle is 26.6° which is greater than 25° ; therefore, the wall friction angle of 25° is suitable for all internal angles of friction that are to be investigated. Equation 11 will give results for inappropriate combinations of internal angles of friction and wall friction angles, so it is up to the user to ensure that appropriate angles are being considered.

6.1 CONSTANT CENTRE SECTION WIDTH

An analysis of equivalent frictions for transfer chutes with constant centre section width was conducted using Equation 11. The variation of transfer chute cross-section is shown in Figure 4 and the results of the analysis are given in Figure 5.



Figure 4. Transfer chute cross-section variation for a constant width centre section. Flow depth reduces.

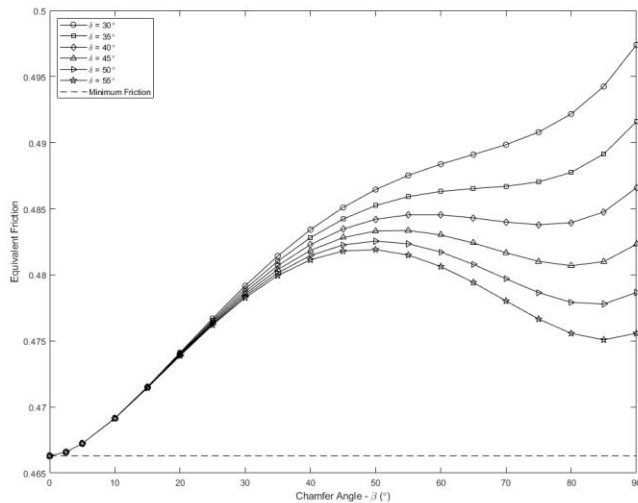


Figure 5. Equivalent friction for constant transfer chute centre section width.

As expected, Equation 11 predicts that the equivalent friction will be identical to the tangent of the wall friction angle when $\beta = 0^\circ$ and that the equivalent friction never drops below this level. The results also show that materials with low internal angles of friction will have higher equivalent frictions when flowing in square cornered transfer chutes. Perhaps surprisingly, the results predict that a square cornered transfer chute could offer a lower equivalent friction when compared to a chamfered transfer chute for bulk materials with high angles of internal friction.

6.2 CONSTANT TOTAL WIDTH

An analysis of equivalent frictions for transfer chutes with constant total width was conducted using Equation 11. The variation of transfer chute cross-sections is shown in Figure 6. For this analysis, the width of the centre section is adjusted to keep the top surface of the bulk material level with the transition from the chamfers to parallel sides. The results of the analysis are given in Figure 7.

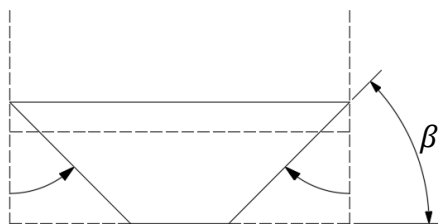


Figure 6. Transfer chute cross-section variation for a constant total width transfer chute. Flow depth increases.

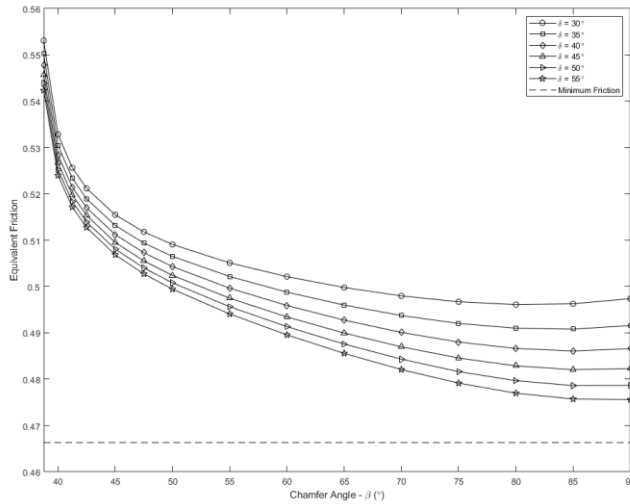


Figure 7. Equivalent friction for constant total transfer chute width.

The results shown in Figure 7, for the square cornered transfer chute are identical to the equivalent results in Section 6.1. As before, the different materials see a benefit to the addition of 85° chamfers. However, here, unlike in the previous section where flow depth decreased as the chamfer angle decreased, the flow depth increases as the chamfer angle decreases. The penalty of increasing flow depth is an increase in equivalent friction which can negate the benefits of chamfers for most materials. This equivalent friction analysis stops at just below 40° as the centre section width needs to be greater than 0 m.

6.3 CONSTANT FLOW DEPTH

An analysis of equivalent frictions for transfer chutes with constant flow depth was conducted using Equation 11. The variation of transfer chute cross-sections is shown in Figure 8. The results of the analysis are given in Figure 9.

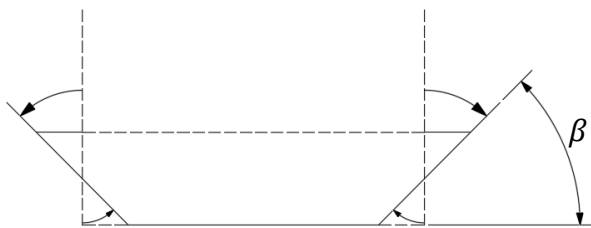


Figure 8. Transfer chute cross-section variation for constant flow depth.

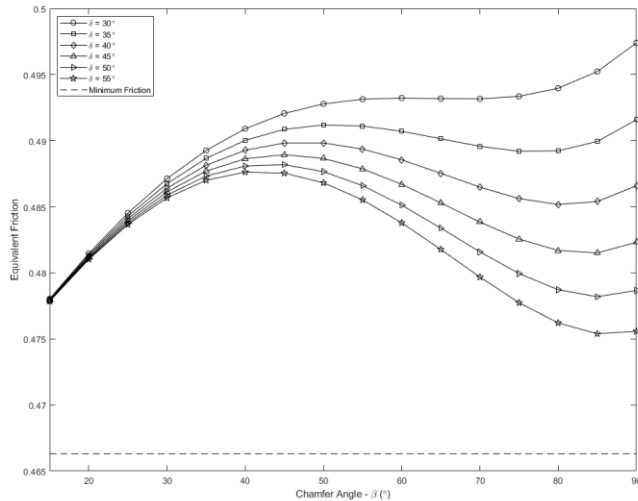


Figure 9. Equivalent friction for constant flow depth.

The results shown in Figure 9, for the square cornered transfer chute are identical to the previous square cornered transfer chute results. The different bulk materials generally see the same changes in equivalent friction as the results in Figure 5; however, because of the constant flow depth, the equivalent frictions are slightly higher than they were when the flow depth was reducing for the cross-sections that were analysed in Figure 5. The data in Figure 9 stop at 15° because the length of the centre section must stay above 0 m.

7 VERIFICATION OF THE EQUIVALENT FRICTION RESULTS WITH DISCRETE ELEMENT MODELLING

The preceding theoretical results need to be corroborated with some other unrelated method. The best alternative is physical testing, but another option is Discrete Element Modelling (DEM). DEM relies on none of the theories used to derive Equation 11; therefore, agreement between Equation 11 and DEM will lend some confidence in the application of the chamfered transfer chute continuum model theory.

A series of different DEM simulations were conducted to replicate some of the results in Figure 5. The geometry used to create the data sets in Figure 5, where the centre section of the transfer chute is kept constant, was replicated in the DEM simulations and particles of a uniform 10mm diameter were added. The particle mass was calibrated and a coefficient for sliding friction was applied to them. In the simulations, the particles were prevented from rotating and the walls were given a friction value of zero. A selection of DEM models is shown in Figure 10. To calculate the equivalent friction from the DEM simulations, the normal loads on the centre section and chamfer surfaces were extracted. The sum of the normal loads was then multiplied by the tangent of the wall friction angle to calculate the frictional resistance force. The frictional resistance force was then divided by the mass force of particles in the simulation to calculate an equivalent friction coefficient that is comparable to the equivalent frictions used in continuum modelling.

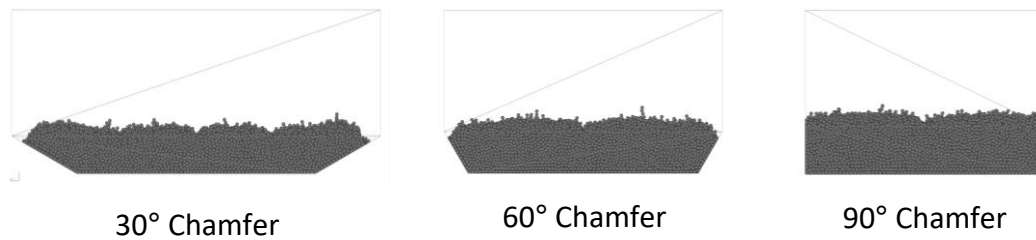


Figure 10. DEM simulation models equivalent to the results in Figure 5.

Comparative results between the DEM simulations and Equation 11 are shown in Figure 11. To appropriately compare the two sets of results, the internal friction angle of the two bulk materials was adjusted manually until a good fit was achieved. The results indicate that for the particle properties used in the DEM simulations to have internal friction angles of 28° and 47° required a particle to particle sliding friction of 0.75 and 0.90 respectively while particle rotation is prevented. The results are compared to a wall friction angle of 25° which is less than the maximum possible wall friction angle of 25.1° , calculated from $\delta = 26^\circ$. Therefore, both materials are appropriate combinations with a wall friction angle of 25° .

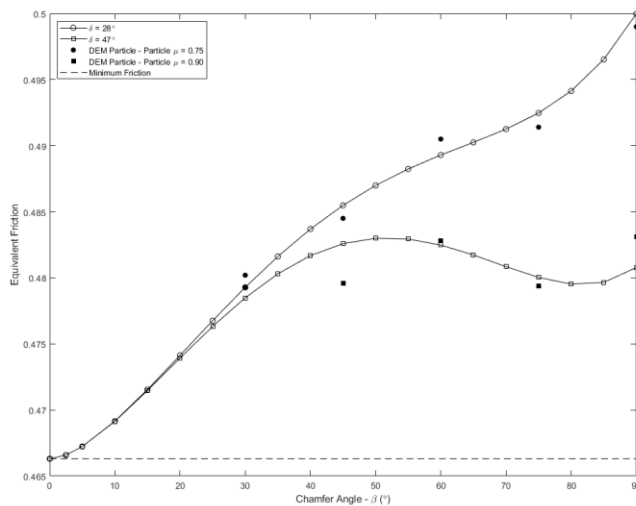


Figure 11. DEM and continuum model comparison.

Despite the crudeness of the DEM simulations, the results of the comparisons between the continuum model are quite good: showing both the predicted levelling off to the equivalent friction for bulk materials with a relatively high internal angle of friction, and a more linear progression for bulk materials with a relatively low internal angle of friction. These results lend confidence to the continuum model theory for equivalent frictions on chamfered transfer chutes.

8 LUMPED MASS CONTINUUM MODELLING OF CHAMFERED TRANSFER CHUTES

The implications of the equivalent friction analysis just presented is best demonstrated with a continuum modelling example. The example presented by Roberts (2003) is updated to compare square cornered transfer chutes with chamfered transfer chutes and materials with different internal angles of friction.

To reiterate the problem, a bulk material is flowing vertically at a rate of 1000 tonnes per hour. The receiving conveyor is five metres below the discharge where the material has an initial, vertical, velocity of 0m/s. The example calculates the flow velocities along four different radii each organized as per the curves in Figure 12. The square cornered transfer chutes are 0.5m wide and the chamfered transfer chutes have a centre section that is 0.5m wide between the chamfers. The chamfer angle is 45°. Two bulk materials with internal angles of friction of 30° and 55° and densities of 800kg/m³ are analysed. The wall friction angle for all transfer chute and bulk material combinations is 25°. The problem is relevant to Figures 4 and 5 where the width of the transfer chute is allowed to widen as the chamfer angle reduces.

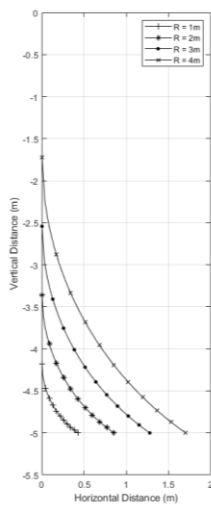


Figure 12. Transfer chute curve profiles used in the analysis.

The velocity results for the bulk material with the internal angle of friction of 30° are shown in Figure 13. As noted in Figure 5, the equivalent friction is lower for the chamfered transfer chute compared to the square cornered transfer chute. This is born out for the relatively higher velocities for the flow in the chamfered transfer chute.

The velocity results for the bulk material with the internal angle of friction of 55° are shown in Figure 14. As noted in Figure 5, the equivalent friction is higher for the chamfered transfer chute compared to the square cornered transfer chute. This is born out for the relatively lower velocities for the flow in the chamfered transfer chute.

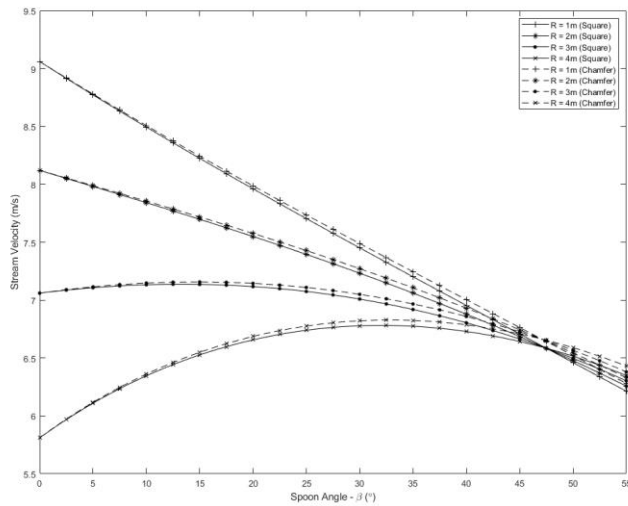


Figure 13. Continuum modelling for a bulk material with an internal angle of friction of 30° . The chamfer angle in this analysis is 45° .

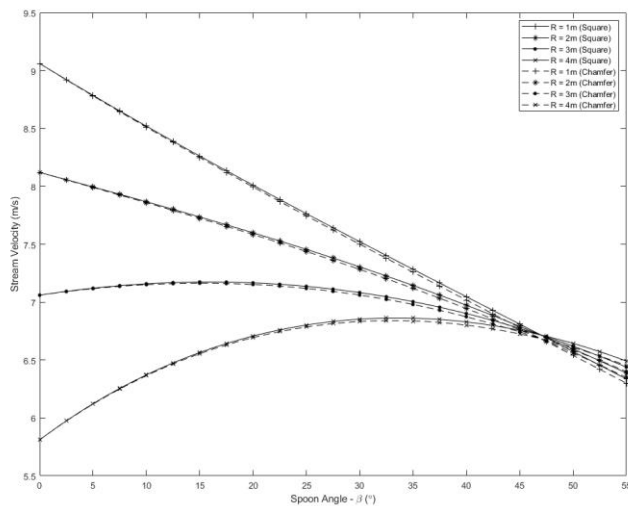


Figure 14. Continuum modelling for a bulk material with an internal angle of friction of 55° . The chamfer angle in this analysis is 45° .

9 DISCUSSION OF EQUIVALENT FRICTION AND RESULTS

The foregoing continuum modelling examples tend to indicate that the effects of transfer chute chamfers have a limited effect on flow velocity within a transfer chute. However, in the absence of other considerations, the modelled transfer chutes are well designed, featuring material flow depths approximately 20% of the transfer chute width. For a less well-designed transfer chute, be it the fault of insufficient material properties, poor calibration practices, a limited transfer chute design envelope or an increased throughput required by the transfer chute's operator for example, then the effect of the chamfers will become more dominant.

The main consequence of a 'less well-designed transfer chute' or the need to add chamfers by removing flow area from the corners is that the material flow depth will

increase. In transfer chute design, flow depth is the main variable that effects the equivalent friction, and everything should be done to reduce the flow depth to improve the performance of the transfer chute.

In Australia, most transfer chute design is done for high internal friction angle materials such as iron ore and coal. The small difference between the flow velocities of the chamfered and non-chamfered transfer chute for the higher angle of internal friction material explains why the continuum model design process has been successful when carried out by ignoring the presence of the chamfers. When a chamfered transfer chute analysis is approximated by considering it as a square cornered transfer chute at the full width of the chamfered transfer chute, the equivalent friction value rises for materials with medium to high internal angles of friction as evident in Figure 7. The increased friction is counteracted by a reduction in flow depth calculated as a consequence of the approximated chute shape, and thus the continuum model predicts appropriate results.

10 FUTURE WORK

During the verification of the equivalent friction equation for chamfers using DEM, an interesting, though perhaps obvious, finding was that the application and release of additional pressure to the material model induced the development of internal shear stresses within the material model that were not totally released when the pressure was removed. The addition of pressure to the DEM material model was an attempt to level out the upper surface of the modelled material to match the assumed flat top surface used in the continuum modelling. The uneven upper surface was caused by the need to pour the particles into the simulation evenly distributed over the width of the model, thus loading more particles on the chamfers than is required. The unevenness of the material model is notable in Figure 10. The model manipulations that generated the internal shear stresses were not representative of the conditions assumed for the equivalent friction theory and the additional stresses increased the measured equivalent friction.

It is possible that Equation 11 is only useful in cases of thin flow, large radius transfer chutes or straight sections of transfer chutes where loose poured conditions, without the influence of additional loads, could be reasonably expected to exist. When additional external loads are acting on the flowing bulk material – centripetal or impact forces for instance – the preceding equations may need to be modified to consider the change in equivalent friction in addition to the increased normal loads that are already considered. The relationship between equivalent friction and additional loads on the bulk material flow needs to be investigated further.

11 CONCLUSION

This paper has presented a continuum modelling equation to calculate the equivalent friction for chamfered transfer chutes. The new equation is used in the same manner as the equivalent friction equation for square cornered transfer chutes and can even replace it.

The equivalent friction equation for chamfered transfer chutes has been corroborated using DEM simulations, and the equivalent friction results for different chamfer angles and material properties has been demonstrated. The equivalent friction equation for chamfered transfer chutes gives the expected results at chamfer angles of 0° and 90° and has been used to calculate flow velocities for different cross-sections and material properties.

The generation of equivalent friction graphs covering materials of different internal friction angles and chamfer angles has shown why ignoring the presence of chamfers in a continuum model has either produced similar results or slightly more conservative results to what would have been calculated with more detailed equations. This was also shown by example where velocity profiles are not greatly different between chamfered and square cornered transfer chutes in some cases.

The equivalent friction equation for chamfered transfer chutes is a useful addition to the field of continuum modelling, provided that the assumptions used in its derivation are adhered to and that the implied limitations are understood.

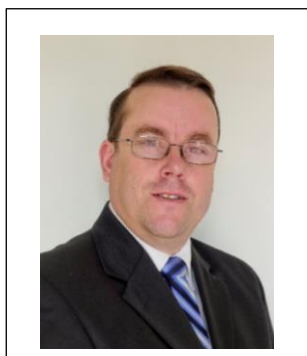
12 NOMENCLATURE

Flow Area	A	$[m^2]$	
Chute Centre Section Width	B	$[m]$	
Coefficient	b	$[m]$	
Chamfer Whetted Length	C	$[m]$	At current position.
Coefficient	c	$[m^3/s]$	
Chamfer Whetted Length	C_0	$[m]$	At start of chute section.
Friction Force	F	$[N/m]$	
Gravity	g	$[m/s^2]$	
Flow Depth	H	$[m]$	At current position.
Flow Depth	H_0	$[m]$	At start of chute section.
Pressure Ratio	K	$[-]$	
Vertical Pressure Ratio	K_v	$[-]$	For vertical chute sides.
Lumped Mass Normal Load	N	$[N/m]$	
Centre Section Normal Load	N_b	$[N/m]$	
Chamfer Normal Load	N_c	$[N/m]$	
Missing Normal Load	N_m	$[N/m]$	
Total Normal Load	N_t	$[N/m]$	
Chute Radius	R	$[m]$	
Distance	s	$[m]$	Along chute section.
Flow Velocity	v	$[m/s]$	
Flow Velocity	v_0	$[m/s]$	At start of chute section.
Chamfer Angle	β	$[^\circ]$	
Internal Angle of Friction	δ	$[^\circ]$	
Angular Position on Chute	θ	$[^\circ]$	0° at vertical section of curve.
Bulk Solid Density	ρ	$[kg/m^3]$	
Wall Friction	μ	$[-]$	
Equivalent Wall Friction	μ_e	$[-]$	
Centre Section Pressure	σ_c	$[N/m^2]$	
Chamfer Pressure	σ_c	$[N/m^2]$	
Minor Principal Pressure	σ_x	$[N/m^2]$	
Vertical Pressure	σ_z	$[N/m^2]$	
Max. Wall Friction Angle	ϕ_s	$[^\circ]$	

13 REFERENCES

- 1 Roberts, A.R. (2003). Chute Performance and Design for Rapid Flow Conditions. *Chemical Engineering and Technology*. Weinheim. Wiley-VCH.

14 ABOUT THE AUTHORS



DR PAUL MUNZENBERGER

Dr Paul Munzenberger has been working as a senior mechanical engineer with Aspec Engineering Pty. Ltd. since 2018. Paul worked as a fitter machinist before becoming a mechanical engineer in 2007 when he joined TUNRA Bulk Solids. Paul has over 20 years' experience maintaining, repairing and conducting engineering and research activities on material handling equipment from samplers to stackers and reclaimers and everything in between.

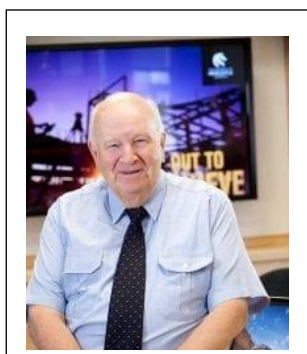
Dr Paul Munzenberger

Aspec Engineering Pty. Ltd.

3/166 Hannell Street, Wickham NSW 2293 Australia

Telephone: (+61 2) 4962 2314

Email: pmunzenberger@aspec.com.au



EMERITUS PROFESSOR ALAN ROBERTS

Emeritus Professor Alan Roberts AM has an outstanding international reputation as a world authority in the field of bulk solids handling. He has a proven international track record in fundamental and applied research, and is highly respected by industry worldwide. He was the founder of TUNRA Bulk Solids in 1975. His contribution to research and consulting spans a period of 50 years and covers almost all aspects in the field of bulk solids handling.

E/Prof Alan Roberts

TUNRA Bulk Solids

The University of Newcastle

University Drive, Callaghan NSW 2308 Australia

Telephone: (+61 2) 4033 9036

Email: Alan.Roberts@newcastle.edu.au



PROFESSOR CRAIG WHEELER

Dr Craig Wheeler is a Professor in the School of Engineering at the University of Newcastle, Australia and an Associate Director of TUNRA Bulk Solids. He worked as a mechanical engineer for BHP Billiton for eleven years and then as a research fellow at the Centre for Bulk Solids and Particulate Technologies for four years. He was appointed as an academic in the Discipline of Mechanical Engineering in 2000.

Prof Craig Wheeler

Centre for Bulk Solids and Particulate Technologies
School of Engineering, The University of Newcastle
University Drive, Callaghan NSW 2308 Australia
Telephone: (+61 2) 4033 9037
Email: Craig.Wheeler@newcastle.edu.au