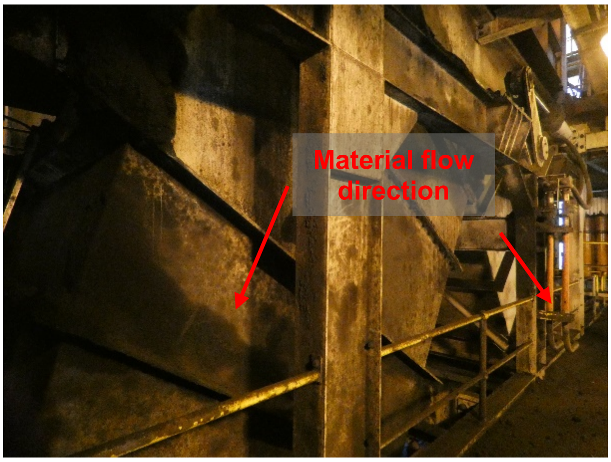
Transfer Chute Analysis with Discrete Element and Continuum Modelling

Paul Munzenberger[1]

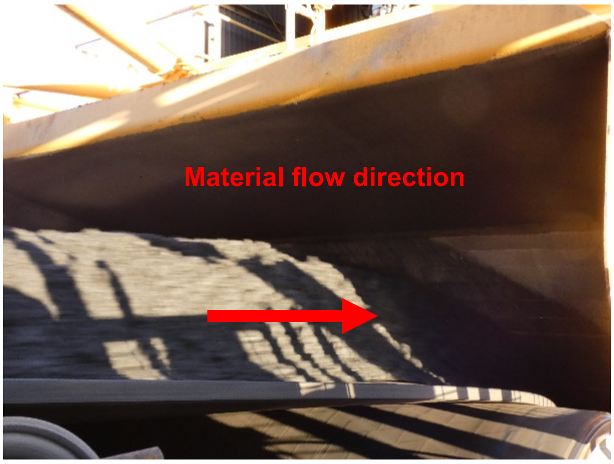
[1]Aspec Engineering Pty Ltd, Newcastle, Australia; pmunzenberger@aspec.com.au

Abstract

Transfer chutes are used in the minerals industry to transfer bulk material between conveyors, storage systems and treatment processes. As with any other part of the handling or processing system, transfer chutes can cause bottlenecks by restricting material flow to less than the design throughput by choking with too much material or by blocking completely. It is important to the success of a transfer chute project that the chute has been designed properly and modelled under a variety of operating conditions to ensure that it will be free of flow problems. An example of a chute is shown in Figure 1 (a), the chute is a diverter chute with a surge capacity nearing 15,000 tonnes per hour; and an example of the bulk material flow, that is modelled with discrete element or continuum modelling to predict chute performance, is shown in Figure 1 (b).



(a)



(b)

Figure 1 Examples of (a) a chute and (b) bulk material flow that is modelled with continuum modelling and DEM Modelling

The most common chute design tool currently used is discrete element modelling (DEM). The other, older, design tool is lumped mass continuum modelling (continuum modelling). This article briefly describes the two tools and looks at how they can be used to complement each other to enable the efficient design of transfer chutes.

1. Discrete Element Modelling

DEM has become a viable chute design tool over the last 15 to 20 years with the introduction of increasingly powerful computers. At its most simple, DEM models a bulk material as a series of spheres which are given appropriate properties such as density, inter-particle and particle-to-wall frictions and adhesion among others. The spheres are modelled as passing through a three-dimensional chute as shown in Figure 2. At each time step of the simulation's progression, the position, linear and rotational velocities and accelerations of the particles are calculated, and collisions are analysed to determine where they will be at the next time step where the calculations are repeated.

DEM software is available from many vendors, is generally easy to use, has a range of visual outputs in the form of images and video footage and can be used to analyse the statistics of each particle if desired. Conversely, the simulation process is computationally expensive and can take from a few hours, for overly simplistic models, to a few days for detailed models and while the simulations will run without user input – overnight for example – the length of the simulation time will lead to a slow iteration process if no other design tools are used. Even more problematic, the most difficult part of the DEM process: the material modelling, is often rushed or guesses are made due to the lack of material property testing.

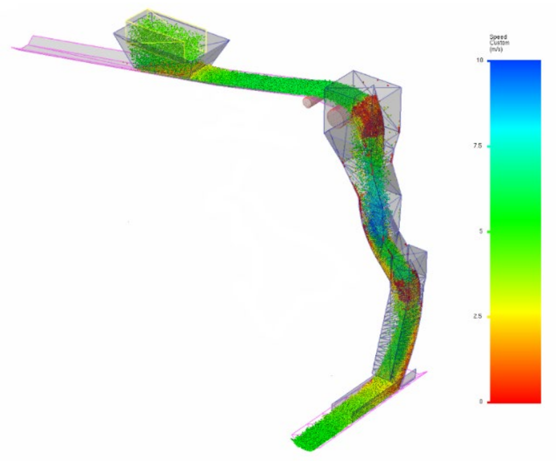


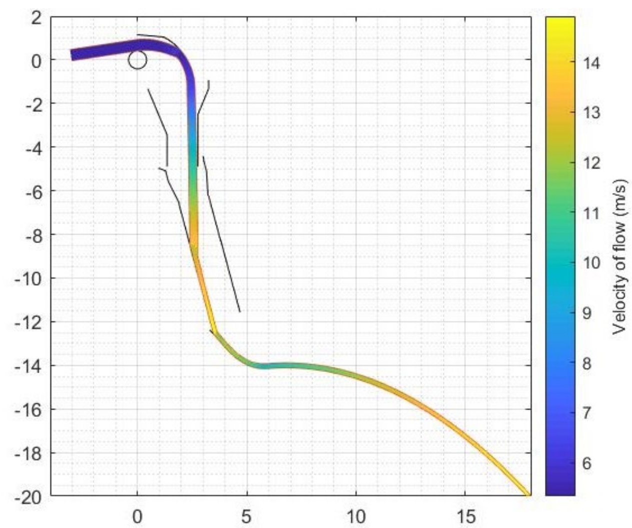
Figure 2 A transfer chute DEM model. The colours represent the velocity of the spheres.

2. Continuum Modelling

Continuum modelling maps the flow of the upper and lower surfaces of a bulk material as it flows from the discharge conveyor to the receiving conveyor, passes through air, impacts the chute and flows along curved or straight chute sections as shown in Figure 2. At each impact point, an equation is used to calculate the material's flow conditions after the impact, traditional dynamics equations are used to calculate trajectories through air and a numerical analysis is conducted for each section of the chute that the flow slides along. At regular stages throughout the predicted material path the velocity and flow area are calculated and checked against the chute design's cross section to ensure there is adequate room for the flow.

Continuum modelling is based on traditional dynamics and tribology equations and chutes are usually modelled in two dimensions with spread sheets that following the path of the flow's centreline. Continuum modelling analysis speeds are relatively quick when using spread sheets, but the true speed of the method can only be achieved with dedicated software that is not commercially available. The method's primary disadvantage is that it requires a strong knowledge of mathematics to implement, especially if the continuum analysis is to be extended to three dimensions.

(a)



(b)

Figure 3 A ship loader chute (a), and the corresponding lumped mass continuum model (b). The coloured contours represent the flow speed.

3. Comparison of Continuum and DEM Analysis

Traditionally, a continuum analysis is a manual process where the conditions of each section of the flow is calculated individually. Companies heavily involved in designing chutes will have automated the continuum modelling process and will be able to produce numerous models and iterations in a short time – with production of contoured material path plots like the one shown in Figure 3 being relatively easy. Unfortunately, companies wishing to have a fast continuum modelling capability will need to develop their own software. On the other hand, DEM modelling is only done by computers and DEM modelling software is easy to use and can be purchased from numerous software providers.

Aside from the actual assessment of the simulation results – a skill also required for continuum modelling – the main area requiring materials handling experience when conducting a DEM analysis is the calibration of the material properties. Unlike with continuum modelling where material properties can be directly entered into the simulation from results that would have already been collected for the design of silos, hoppers and feeders, DEM model parameters can only be determined through the replication of physical tests that were carried out on the bulk material and which are additional to the typical shear cell tests. The DEM material calibration process is itself time consuming – more so if a new round of material testing is required – with advanced DEM software having many variables that need to be determined.

The main advantage that continuum modelling offers over DEM is speed. With appropriate software, many continuum model simulations can be completed, covering a range of possible chute designs, before the calibration of the DEM material model would be complete. The trade-off is that the range of result options available with DEM software is superior to continuum modelling. The output of continuum modelling can be extensive, but results are only available if the time is spent developing spread sheets or scripts that can calculate them.

4. Chute Design with Combined Continuum and DEM Analyses

A modern scope of work will likely specify the compulsory inclusion of DEM in the design process. However, this doesn't, and shouldn't preclude the use of continuum modelling in the project. In one sense, just as it is expected that finite element modelling results are backed by corroborating hand calculations, it should also be expected that any DEM chute analysis is presented alongside corroborating continuum modelling calculations. However, the usefulness of continuum modelling goes beyond verifying the DEM results as it can also be used to inform the chute design before any DEM simulations are started.

As has already been noted, when a chute project is awarded, there will usually be material properties available or in the process of being measured. These results will be directly applicable to the continuum model and often don't include results that are useful for DEM simulations. This situation means that the DEM chute simulations will be delayed by months, while DEM material properties are measured, unless approximations are made to move the chute design forward. While waiting for DEM specific material properties, it is possible to use the already available material properties to design the chute with a continuum model and carry out a limited number of compulsory DEM simulations at the end of the project. This has the dual benefit of an efficient design process and a timely completion of the project. Even if the appropriate material properties are available at the outset, it is still beneficial to conduct the project in the described manner.

If the designer's preference is to conduct the bulk of the chute design with DEM simulations then, as a minimum, a continuum model should be consulted to determine the chute's minimum slope or cut-off angle. The continuum model requires much less design work to be completed and can provide chute cut-off angles for several chute design options in a relatively short time. The early availability of a chute cut-off angle will save considerable redesign time when angle changes are required to a mature chute design that correct problems with surfaces found to be overly shallow at a late stage in analysis progression. The continuum model is also better suited for quick calculation of impact angles and impact velocities that are sometimes required as a project result.

5. Conclusion

Transfer chute design can be completed from start to finish with either DEM or continuum modelling. However, if for nothing else, the confidence that is gained from being able to compare results that started from different material inputs and used different simulation procedures is invaluable; especially given the high cost of designing, manufacturing and installing a new chute. It is easy to get enamoured by the DEM modelling process and to forget how much time is spent making simulation corrections and design changes. It is also easy to dismiss the comparatively boring and difficult numbers world of continuum modelling. However, combining DEM and continuum modelling allows the disadvantages of each process to be offset by the other to produce a viable result with all the required details and confidence in a timely manner.