Discrete Element Modelling (DEM)

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Abstract

Recent advancements in Discrete Element Modelling, has gained the attention from industries ranging from oil and gas to the entertainment industry and it will possibly become one of the most important advancements to the mining industry. This attracts an increase in ongoing research in this area, to study models behind DEM, improve simulations, and thus improve efficiency in these industries.

In this project, we will be investigating DEM, and evaluating a DEM software package, EDEM, by studying the mathematical models used in DEM. Due to the ongoing need to design an accurate belt conveyor, for efficient transfer of particles, this research will investigate the accuracy of a transfer configuration modelled by DEM. This analysis was done by computing particle trajectories from conveyor belts, and the interactions between particles and particles, and between particles and the transfer chute. Comparisons between simulations from EDEM and another DEM software package, ChuteMaven, with the actual experimental facility done in University of Wollongong, will be done to determine the accuracy of EDEM.

1.0 Introduction

Some thirty years ago, particle modelling was introduced into geomechanics. Ever since then, scientists have taken a keen interest in studying granular behaviour. This in turn has led to the development of Discrete (Distinct) Element Method by Peter Cundall in 1971 who applied it to resolve problems in rock mechanics. Even though Discrete Element Method was developed in 1971, it was only officially named by Cundall and O. Strack in 1979 publications.

Discrete element method (DEM) is a family of numerical methods that have been designed to solve real-world problems which display complex discontinuous mechanical behaviour in engineering and applied science disciplines. It has been used to study particle flow behaviour in applications which includes: drilling, blasting, cutting, block caving, digging, scraping, crushing, flow regulating (eg. transfer chutes), sliding, vibrating, storing and reclaiming in bins and stockpiles, classifying, segregating, grinding, polishing, coating, floating and mixing.

DEM simulations involve solving Newton's law of motion for trajectories, spin and orientation of every particle in the flow. It is able to model each collision between particles and between the surrounding boundary objects using Coulomb's law and various contact models. In addition, it is also able to predict and model the dynamic behaviour of particles in a physical system by defining material properties such as its Shear's modulus, Poisson's ratio, density and coefficient of restitution, static and rolling friction.

2.1.5 Coefficient of Static Friction

Static friction occurs when the two objects are not moving relative to each other. Therefore, coefficient of static friction defines friction when no movements exist between the two surfaces. Static friction force must be overcome by an applied force before an object will move. The maximum possible friction force between two surfaces before sliding begins is the product of the coefficient of static friction and the normal force: $F_{\max} = \mu_s N$, with μ_s being the coefficient of static friction. Any force larger than $F_{\max}$ will overcome the force of static friction and cause sliding to occur. The instant sliding occurs static friction is no longer relevant. Obviously, the package uses non-static friction to be the same as static friction.

The coefficient of static friction between two solid surfaces is defined as the ratio of the tangential force (F) required to produce sliding, divided by the normal force between surfaces (N)

$$F_{\max} = \mu_s N$$

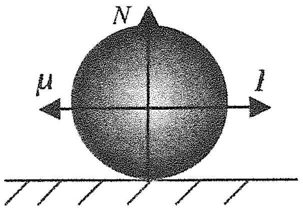

Figure 2 Static Friction

2.1.5 Coefficient of Rolling Friction

Rolling friction is the resistance that occurs when an object rolls. It is caused primarily by the interference of small indentations formed as one surface rolls over another. This is the idea behind the frictional forces involved with wheels, cylinders, and spheres. The force of rolling resistance is defined as

$$F = C_{rr} N_f / R$$

where F is the resistant force,
C_{rr} is the coefficient of rolling friction (CRF)
N_f is the normal force and R is the radius of sphere.

This is normally small (0.01) and is sometimes ignored in DEM.

2.2 Contact Models

2.2.1 Linear Spring Contact Model

The damped linear spring contact force model is based on the work by Cundall and Strack (1979). A linear spring with stiffness k_n is in parallel with a dashpot with coefficient c_n. The magnitude of the normal force between two particles, F_n, is:

$$F_N = k_n \delta_n + c_n \dot{\delta}_n$$

where δ_n is the overlap distance
$\dot{\delta}_n$ is the overlap

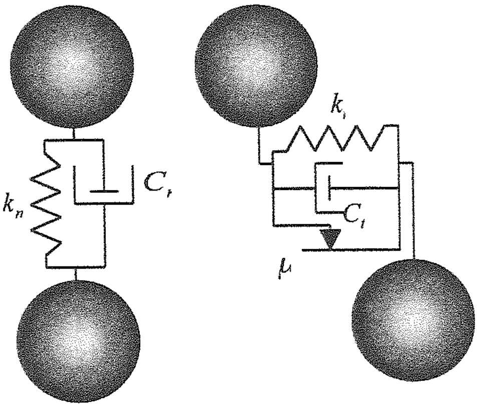

Figure3 Linear Spring Contact Model Between two particles in normal and shear directions

Overlap distance is the length that two model particles are overlapping when colliding due to ordinary differential equation (ODE) discrete time stepping, this can sometimes be substantial. (See 2.3)

Similar force is applied to the tangential direction.

The tangential stiffness is usually estimated as a ratio of the normal spring stiffness (Cundall, 1979). The dashpot coefficient is calculated using the tangential stiffness in the equation above. The tangential force is computed as:

$F_t = \min\left(k_t\delta_t + c_t\dot{\delta}_t, \mu F_N\right)$ where k_t and c_t are the tangential spring and dashpot coefficient
μ is the coefficient of friction

2.2.2 Hertz Mindlin (H-M) No Slip Contact Model

H-M model is based upon the work of Mindlin (1949).

The normal force, F_n is given by

$F_n = \frac{4}{3}E^*\sqrt{R^*}\delta_n^{3/2}$ where **E^*** is the equivalent Young's modulus
R^* the equivalent radius
δ_N the normal overlap.

Additionally, there is a damping force, F_n^d, given by

$F_n^d = -2\sqrt{\frac{5}{6}}\beta\sqrt{S_n m^*}\vec{v_n^{rel}}$ where m* is the equivalent mass
$\vec{v_n^{rel}}$ is the normal component of the relative velocity

and β and S_n (the normal stiffness) are given by

$\beta = \frac{\ln e}{\sqrt{\ln^2 e + \pi^2}}$, $S_n = 2Y^*\sqrt{R^*\delta_n}$ where e is the coefficient of restitution

The tangential force, F_t, depends on the tangential overlap δ_t and the tangential stiffness S_t.

$\vec{F_t} = -S_t\vec{\delta_t}$ with $S_t = 8G^*\sqrt{R^*\delta_n}$

Additionally, there is a tangential damping force, $\vec{F_t^d}$

$\vec{F_t^d} = -2\sqrt{\frac{5}{6}}\beta\sqrt{S_t m^*}\vec{v_t^{rel}}$ where $\vec{v_n^{rel}}$ is the relative tangential velocity.

The tangential force is limited by Coulomb friction, $\mu_s F_n$ where μ_s is the coefficient of static friction.

2.3 Time Stepping

Time step is the amount of time between ODE integration iterations during the simulation. The smaller the time step, the more data points are produced. A large number of data points produce results with a very fine level of detail; however computation time will be larger due to the increased number of calculations that take place.

The Rayleigh time step, T_R, is the idealised DEM time step and is calculated automatically by EDEM. It can be defined as the time taken for a shear wave to propagate through a solid particle. It is therefore a theoretical maximum time step for a DEM simulation of quasi-static particulate collection in which the coordination number (total number of contacts per particle in one time step) for each particle remains above 1. If the time step is too small, simulations will take a long time to run. If the time step is too large, particles can behave erratically (overlap could become non physical)

Rayleigh time step is given by:

$$T_R = \pi R\left(\frac{\rho}{G}\right)^{\frac{1}{2}} \div 0.1631v + 0.8766$$

where R is the particle's radius,
ρ its density,
G is the shear's modulus
v the Poisson's ratio.

2.4 Space Settings

The main computational challenge in DEM simulation is the detection of contacts. By dividing the domain into grid cells, the simulator will be able to check each cell and analyse only those that contain two or more elements, thus reducing computation time. As the grid length decreases, fewer elements are assigned to each grid cell and contacts become easier to resolve. The fewer particles per grid cell, the more efficient the simulator.

3.0 Methodolology

This project will be looking at modelling a transfer configuration using EDEM and gather data of particle movements. The data collected will be used to compare with raw data gathered from the actual experimental facility, done in University of Wollongong (UW). We will also be comparing the data computed by EDEM with the data computed by ChuteMaven, another DEM software package which UW is using.

However, before the design of the transfer configuration was finalised, we started the project by doing a literature search, to gain more depth of the mathematical models used in DEM. After which, we began learning how to use EDEM, with the help of the user guide provided, and LEAP Australia.

3.1 Trial Model

In the initial stage of our project, we decided to design a simple transfer model in EDEM, as seen in Figure 4, to get a general concept of a transfer configuration, and to explore EDEM. We created a rock particle made up of 3 spheres, to be used in our model. The particles will be moving on the belt, at a speed of 2m/s, falling with gravity down the transfer chute, and falling onto a second conveyor belt moving at a speed of 2m/s.

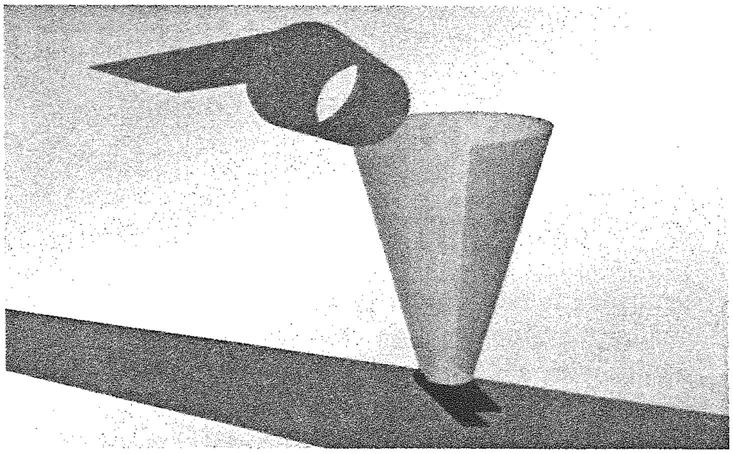

Figure 4 Design of Trial Model in EDEM

3.2 Variables and Aim of trial model

We will be observing how different time steps (as a percentage of the Rayleigh time step) and grid size (R min) would affect our results and computation time. At the same time, we will be varying the number of particles created per sec, and contact models (Linear Spring and Hertz – Mindlin).

Time step (%)	Particle Per sec	Grid Size	Contact model	Particle Per sec	Grid size	Contact model	Particle Per sec	Grid size	Contact model
75	100	20.5	Linear	200	20.5	Linear	400	20.5	Linear
75	100	30.5	Linear	200	30.5	Linear	400	30.5	Linear
75	100	40.5	Linear	200	40.5	Linear	400	40.5	Linear
75	100	20.5	Hertz	200	20.5	Hertz	400	20.5	Hertz
75	100	30.5	Hertz	200	30.5	Hertz	400	30.5	Hertz
75	100	40.5	Hertz	200	40.5	Hertz	400	40.5	Hertz
50	100	20.5	Linear	200	20.5	Linear	400	20.5	Linear
50	100	30.5	Linear	200	30.5	Linear	400	30.5	Linear
50	100	40.5	Linear	200	40.5	Linear	400	40.5	Linear
50	100	20.5	Hertz	200	20.5	Hertz	400	20.5	Hertz
50	100	30.5	Hertz	200	30.5	Hertz	400	30.5	Hertz
50	100	40.5	Hertz	200	40.5	Hertz	400	40.5	Hertz
25	100	20.5	Linear	200	20.5	Linear	400	20.5	Linear
25	100	30.5	Linear	200	30.5	Linear	400	30.5	Linear
25	100	40.5	Linear	200	40.5	Linear	400	40.5	Linear
25	100	20.5	Hertz	200	20.5	Hertz	400	20.5	Hertz
25	100	30.5	Hertz	200	30.5	Hertz	400	30.5	Hertz
25	100	40.5	Hertz	200	40.5	Hertz	400	40.5	Hertz

Table 1 Parameters for Varying: Time Step (% of Rayleigh time step), Grid Size (R min), Contact Model – Linear spring (Linear) and Hertz – Mindlin (Hertz)

We will be exporting results from the simulations, and compare the different results obtained with respect to the contact forces (eg normal force, tangential force) between particles - particles and particles – geometry, energy (eg kinetic, potential) of the particles, and velocity.

An example of a simulation can be seen in Figure 5

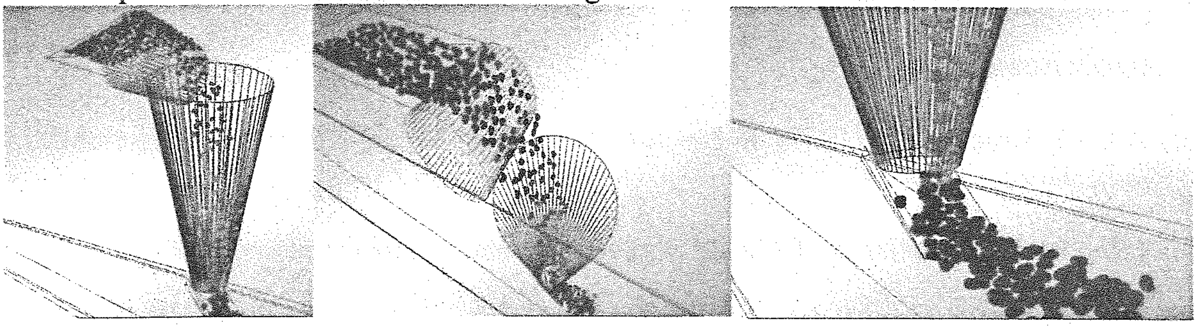

Figure 5 Simulations being run in EDEM

3.3 Actual experimental model

The actual model, designed by Rio Tinto, consists of 3 conveyor belts and 3 transfer chute. The design will be drawn in AUTOCAD, a computer aided design (CAD) software tool, and imported into EDEM, where we will run our DEM simulation.

In the actual experimental facility, a high speed camera will be incorporated into the experimental test program to allow direct measurement of particle velocities through the transfer chutes being investigated. One side of the transfer chute will be made of Perspex to allow visualisation. The actual experiment would be conducted by University of Wollongong.

UW would also be conducting the similar DEM simulation, and will be using ChuteMaven, a specialist belt chute DEM software package, to perform the task.

3.4 Aim of experimental model

The main goals of the project are to build an experimental database of results relating to;

- Several transfer chute designs supplied by Rio Tinto
- Various granular materials including materials such as white plastic pellets for the commissioning process, wheat or similar, iron ore or similar of interest to Rio Tinto.
- Various conveyor belt speeds to look at the effect of slow and fast trajectories into the transfer chute.
- Various product feed rates

Combining the results from both the experimental and both simulation components of the project should allow validation of the DEM process.

3.0 Conclusion

This paper presents a general overview of the project, and looks into DEM. Simulations of the trial model have began, and with the completion of the 54 simulations, we will be able to analyse the results and make a comparison.

At the time of writing, the actual experimental facility is still being set up, and we have not obtained the CAD design of the model. When the test facility is completed, we may be able to begin our simulation of the actual model, and make an evaluation of EDEM.

4.0 References

Cundall, P.A. & Strack, O.J. (1979) A Discrete Numerical Model for granular assemblies, *Geotechnique*, 29 pp. 47 – 75.

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EDEM Userguide, DEM-Solutions, http://www.dem-solutions.com.