Rocky Discrete Element Method Package

The Discrete Element Method (DEM) is a relatively new technique which is gaining great popularity with the advancements of computer technology. This approach is used for the simulation of granular materials, which consist of a large number of solid particles. Continuum equations for this type of material are very difficult to derive for a general flow case. To avoid this problem, the Discrete Element Method relies on the simulation of the motion of every solid particle in the system of interest. The interaction of granular particles with each other and system boundaries are traced at every time step of the simulation.

Rocky is very powerful DEM package marketed by Granular Dynamics International, LLC. It is a shared-memory parallel software which allows the fast solution of granular mechanics problems. It has several capabilities that are unique in the commercial DEM world; these capabilities include true non round particle shapes, the ability to simulate breakage without loss of mass and volume, the simulation of shape change for boundary surfaces due to wear, amongst others. The package is extremely popular in the mining industry and is gaining popularity for other applications related to solid particles flows.

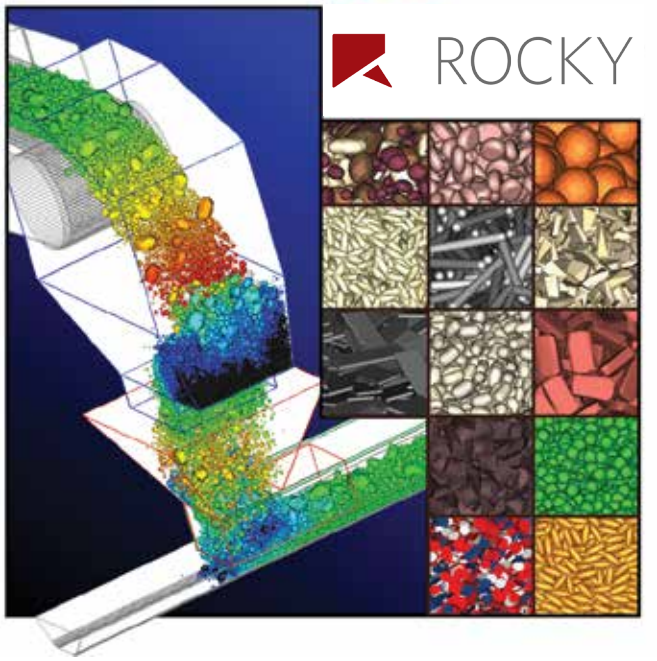

Figure 1. A picture of a conveyor transfer chute simulated by Rocky DEM package and examples of particle shapes available in Rocky

Brief Description of Discrete Element Method

The Discrete Element Method deals with simulations of the flow of granular materials, consisting of many solid particles. Examples of these material types include sand, ore, grain and so forth. These materials are very common in engineering applications and the ability to predict their flow characteristics is an extremely important task. However, unlike deformable solids and fluids, attempts to derive accurate equations of flow and motion in continuum form failed. These equations have been found for only two extremes – the first one is static situations (the elastic-plastic or rigid-plastic approach in soil mechanics) and rapid granular flow (this is a mathematical abstraction which is not applicable for particle flow with realistic energy dissipation and under the influence of gravity). Unfortunately most of flow regimes for granular materials lie between these two extremes and accurate continuum solutions for them are not available. The Discrete Element Method is relatively new technique which deals with this problem by "brute force" - namely by simulating every particle of the granular material in the flow subject to contact and external forces. With this approach one does not need to know the equations of state and motion of granular media; only contact interaction laws are needed and a variety of reliable contact models exist for this purpose. Apart from that the other important advantage of DEM compared to continuum approach is that information is obtained on the particle scale. Sometimes this particle-scale information is essential: for example, the prediction of particles breakage when energy applied to every particle in the system has to be calculated.

While the idea behind DEM is extremely simple, its implementation is not straightforward. The technique relies strongly on computer power and efficient modern parallel programming techniques; without them a DEM program will run for very long time and will be impractical for engineering applications. Recent advances on these fronts have made DEM a good practical tool for engineering simulations.

History of Rocky DEM Package

Rocky is a relatively new DEM package: the development of the code started less than four years ago. However the code is based on the success of in-house DEM solutions developed by Conveyor Dynamics, Inc. from 1995. These in-house codes did not have any user interfaces; therefore the interface for Rocky is relatively new but the solver is very mature. The first version of the code released in summer 2011 was designed for the simulations of transfer chutes only; later, the code interface was updated to add grinding mill simulations. Starting from Rocky 2.0 released in the middle of 2012 the code has been developed and marketed as a general-purpose DEM code. The code is now being developed by Granular Dynamics International, LLC in collaboration with the Engineering Simulation and Scientific Software Company (ESSS).

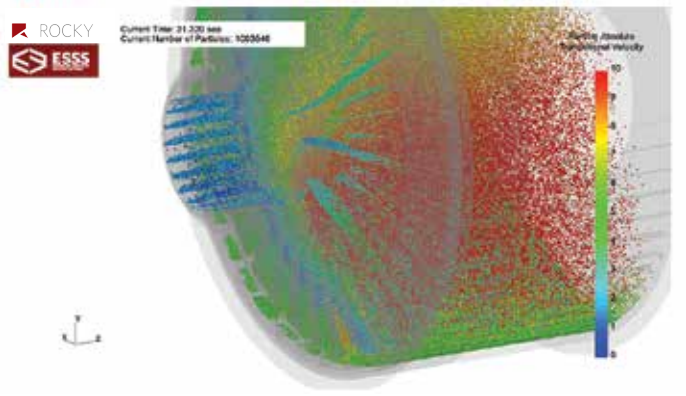

Figure 2. Simulation of particles flow inside grinding mill. Over a million of particles were used in this simulation

Unique Capabilities and Example of Applications

There are number of DEM codes in the market these days and a user now has a choice of DEM packages - both commercial and open-source. Compared to these packages, Rocky has several capabilities that are unique in both the commercial and open-source world. We are going to describe here only the most important ones; descriptions that will necessarily be brief in view of the space available in this paper.

First of all, Rocky was developed with actual practical engineers in mind. The information a user will obtain from the software is not just a collection of pretty pictures and movies but parameters that are important for the engineers. These parameters are power draw on all moving bodies, shear and impact wear parameters, forces, flow rates and so on. The models that are incorporate with the software are real-world physical ones: they are extensively tested both internally by the company on many consulting projects and through our collaboration with universities worldwide. We believe the ability to predict the real-world rather than virtual-world result is the most important characteristic of the software.

The other important feature of Rocky package is the ability to simulate true non-round particles. Other DEM codes rely on clusters of spheres for this purpose, but in Rocky the shape you see on the screen is the actual shape being simulated. This allows us to simulate shapes that are closer to reality and also properly simulate breakage of the particles (which is another unique feature of Rocky) without the loss of mass or volume that is unavoidable with spherical clusters. Some examples of particle shapes that could be created and simulated in Rocky are presented on Figure 1. Also shown in this figure is very typical example of a Rocky application, simulating the performance of a transfer chute. A transfer chute is a gravity device very widely used in mining industry for sharp changes of the direction of material conveyance.

Figure 2 presents another example from the mining industry, the simulation of a full grinding mill. This particular simulation has over a million particles and over seven hundred thousand boundary elements, which is considered to be quite large by DEM standards. Rocky is an efficient shared memory parallel code and can handle this simulation quite quickly.

Figure 3 presents one more unique feature of Rocky, the ability to simulate physical wear of the boundaries. The software collects shear work applied by particles to the boundary and removes boundary volume proportional to this wear work. This feature is extremely useful for predicting the characteristics of particle flows where they are affected by boundary changes due to wear.

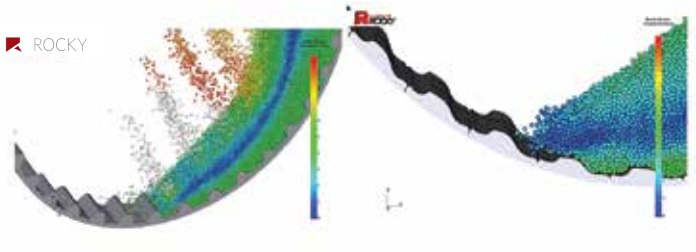

Figure 3. Prediction of wear of a grinding mill lifters inside Rocky. Presented on the left-hand side of the picture is slice of the mill with new lifters and on the right-hand side the same slice at the end of wear simulation process

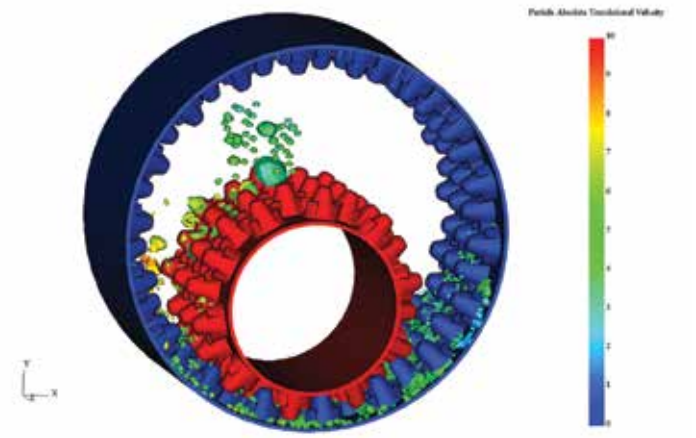

Figure 4. Simulation of particles breakage inside concept of a new grinding device (CAHM -Conjugate Anvil and Hammer Mill).

Breakage simulation is another important feature of Rocky due to be released in the next version. The breakage model in Rocky combines models from the mining and gaming industries for the prediction of particle energy, strength and fragment generation during the breakage event. An example of the model application is presented on Figure 4 - this is a new conceptual device (Conjugated Anvil and Hammer Mill) being developed by Conveyor Dynamics, Inc. for particle comminution processes in the mining industry.

Starting from Rocky 2.2.0 the software can be coupled with the ANSYS Structural and ANSYS Fluent packages. The coupling is one-way at this stage, with work now in progress to provide two-way coupling in the near future. The forces applied by particles to the boundaries can be exported into the ANSYS structural package and the resulting deformations can be calculated. An example of this type of simulation is presented on Figure 5. For this case, a simulation of the motion of particles on a vibrating screen

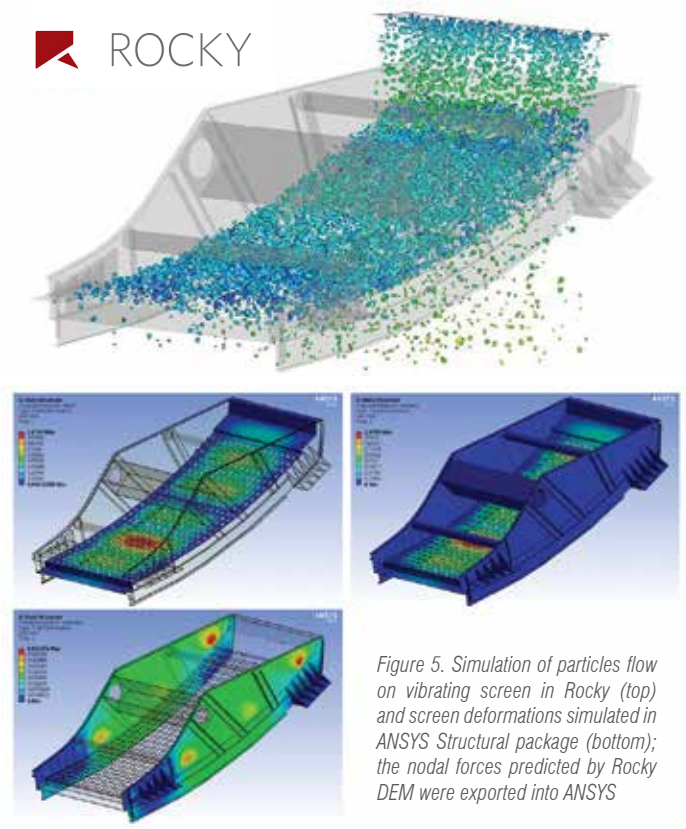

Figure 5. Simulation of particles flow on vibrating screen in Rocky (top) and screen deformations simulated in ANSYS Structural package (bottom); the nodal forces predicted by Rocky DEM were exported into ANSYS

was carried out and the nodal forces applied by the particles were exported to ANSYS Structural to permit the screen frame deformation to be calculated, in addition to the results obtained from Rocky package alone (such as screening efficiency and screen wear characteristics).
The coupling with ANSYS Fluent can be done for both the particles driving the flow of fluid (such as the airflow created around transfer chutes frame caused by falling ore particles) and the fluid driving the flow of particles. In the first case, the continuum parameters of particle flow are calculated inside Rocky on the Fluent mesh and provided via User-Defined Functions to the Fluent solver. In the second case, Fluent case and data files are read directly into Rocky and forces applied by the fluid to the particles are calculated inside the DEM package. The first coupling approach is validated against experimental data obtained at TUNRA laboratories (University of Newcastle, Australia) for airflow around a transfer chute and the agreement with experimental data was excellent. The parent company responsible for the development of Rocky is in the mining industry, with a natural consequence that the majority of its users have also been in this sector. However during recent months the software has been gaining popularity in other industries such as agriculture (for example, the corn flow simulation of Figure 6), pharmaceuticals (where Rocky is being used for tablet coating simulation), materials handling, the construction industry (see Figures 7 and 8 – the simulation of soil flow around a conveyor frame and the simulation of a truck loading station) and many others. There is really no limit to the range of industries to which Rocky may be applied - it suitable for any case where the motion of many solid particles has to be accurately predicted.

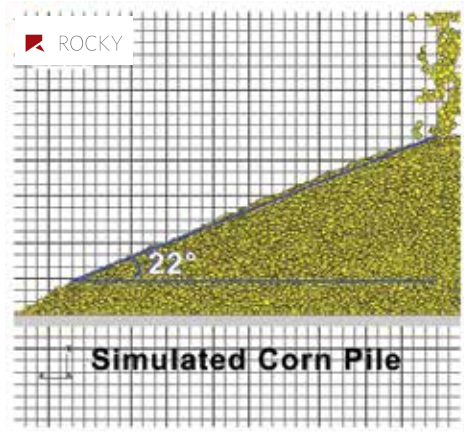

Figure 6. Simulation of corn flow with Rocky DEM package

Future Plants for Software Development

Rocky has historically benefitted from very rapid development. However, even this pace is about to see a very significant increase! Granular Dynamics International, LLC is joining forces with the Engineering Simulation and Scientific Software Company to develop and marked the software. The new version of Rocky 3.0.0 due to be released early next year will feature an advanced new interface with many new features available for the analysis of particles flows. The two-way coupling with ANSYS software has also been planned for the near future. We are also working actively on the improvement of Rocky's speed to enable even larger problems to be handled, tracking many millions of non-round particles in a reasonable amount of computer time.

Conclusions

Presented in this paper is a very brief description of the Rocky Discrete Element package. This package is an extremely powerful tool for the simulations of the flow of granular materials. The package can be very useful for engineers and researchers from a variety of industries.

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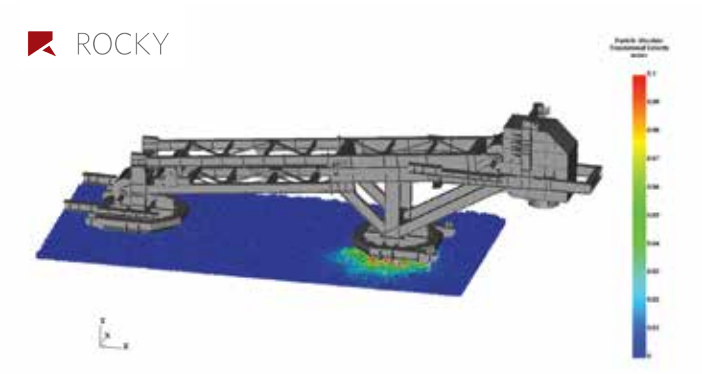
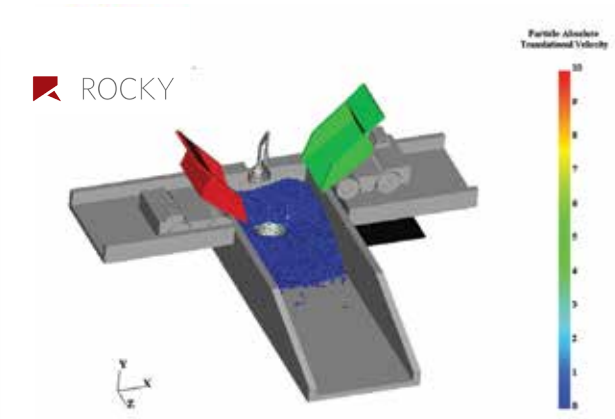


Figure 7. Simulation of soil flow around shifting conveyor frame



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