Particle cluster drop

This example demonstrates the use of clustering in the discrete element method (DEM) in Abaqus.

This page discusses:

Products: Abaqus/Explicit

Application description

In this example we simulate the deposition of a batch of gravel on a surface.

Commercial gravel is produced by crushing stones and grading the crushed aggregates by size into batches. In material handling plants, stone aggregates are transported by conveyor belts and deposited on a surface. Stone aggregates are rarely spherical in shape, and the shape and the size of aggregates influences the contact interaction between the aggregates. In general, the interlocking of irregularly shaped grains impacts the bulk behavior of granular materials.

To improve the fidelity of a discrete element analysis, it is important to describe the grain shape and the grain size as accurately as possible. In this simplified example a collection of limestone aggregates is dropped onto a rigid floor under gravity loading. We use particle clustering to describe the nonspherical shape of the aggregates.

Geometry

In general, commercially produced aggregates exhibit less variation in size and shape compared to naturally occurring gravel. For this simplified model we assume that all aggregates have an identical oblong geometry. The length of each aggregate is 40 mm, and the width is 20 mm. Figure 1 shows the shape and size of the aggregate. Since clustering might involve overlapped particles, computing the mass and inertia of a cluster directly from individual spherical particles results in incorrect mass and inertia values for the original gravel geometry. Instead, you should directly specify the mass and inertia values of the original oblong shaped body. The oblong shape here consists of a cylinder and two hemispheres. Referring to the radius, R, and length, h, of the oblong aggregate (as shown in Figure 1) and using the density, ρ, of limestone, we can compute the mass and inertia of the aggregate using the following equations:

$$M_{hemisphere} = \frac{2}{3}\pi R^3 \rho$$
$$M_{cylinder} = \pi R^2 h \rho$$
$$Mass = M_{cylinder} + 2M_{hemisphere}$$

The oblong body is aligned along the y-axis. The inertia about the y-axis can be computed using the following equations:

$$I_y^{cylinder} = \frac{1}{2} M_{cylinder} R^2$$
$$I_y^{hemisphere} = \frac{2}{5} M_{hemisphere} R^2$$
$$I_y = I_y^{cylinder} + 2I_y^{hemisphere}$$

The inertias about the x- and z-axes can be computed using the following equations:

$$I_x^{hemisphere} = I_z^{hemisphere} = \frac{83}{320} M_{hemisphere} R^2$$
$$I_x^{cylinder} = I_z^{cylinder} = \frac{1}{12} M_{cylinder} \left(3R^2 + h^2\right)$$
$$I_x = I_z = I_x^{cylinder} + 2I_x^{hemisphere} + 2M_{hemisphere}\left(\frac{3}{8}R + \frac{h}{2}\right)^2$$

Plugging in the values of R and h shown in Figure 1 and using density $\rho = 2500 \times 10^{-9}$ kg/mm^3, the mass of each cluster computes to 2.61797×10^{-05} kg and the mass moments of the inertia components are $I_{xx} = 0.003168$ kg mm^2, $I_{yy} = 0.001204$ kg mm^2, and $I_{zz} = 0.003168$ kg mm^2. All other components of the mass moment of inertia have a value of zero.

Abaqus modeling approaches and simulation techniques

The discrete element method (DEM) is used to simulate the piling of the aggregates being dropped onto a rigid floor under gravity.

Mesh design

We model the oblong aggregate as shown in the left image of Figure 1 with a DEM cluster. Each cluster consists of one parent particle and two child particles. The parent particle has a radius of 10mm. The parent particles are defined as PD3D elements. The child particles have the same size as the parent particles, and they overlap with the parent particle by one particle radius. The child and parent particles are aligned collinearly with the child particles positioned on the opposite ends of the parent particle.

The right image in Figure 1 shows the different parameters that are used to define the geometry of the cluster in a local axes system that is centered on the parent particle. In this model the local axes is aligned with the global axes. The parameters α_1 and α_2 define the offset of the two child particles, respectively, in terms of the radius R_p of the parent particle. Similarly, parameters β_1 and β_2 define the size of the two child particles, respectively, in terms of R_p. The orientation of the two child particles in the local axes is defined by the spherical angles θ_1,θ_2, β_1, and β_2, respectively. Figure 1 also shows the values of all the parameters used in the model.

For simplicity, we use only three particles to approximate the oblong shape of the cluster. While the ends of the cluster are smooth, the sides of the cluster have a dimpled shape as can be see in Figure 1. The shape of the aggregate can be described more accurately using additional child particles. Even with many child particles, the sides have some degree of nonsmoothness. This is a limitation of clustering spherical particles to represent any smooth geometry.

There are a total of 4839 clusters in the model. The clusters are initially positioned in layers above the plate as shown in Figure 2. The closest layer is 100 mm above the plate, and the farthest layer is 800 mm above the plate. The floor is meshed using S4R elements.

Materials

The particle clusters in this model have properties of limestone, and the plate is modeled with steel.

	Limestone	Steel
Young's modulus	2.0×10^4 N/mm^2	2.08×10^5 N/mm^2
Density	2500×10^{-9} kg/mm^3	7850×10^{-9} kg/mm^3
Poisson's ratio	0.25	0.3

The particle clusters in the model behave like rigid bodies. The Young's modulus and Poisson's ratio values for the limestone are used for Hertzian contact interaction.

Initial conditions

The particle clusters fall freely under gravity with an initial velocity of 0.0 mm/s.

Boundary conditions

The displacement degrees of freedom at all nodes of the plate are held fixed.

Loads

The aggregates drop freely under acceleration due to gravity of 9810 mm/s^2 that acts in the vertical direction normal to the plate.

Interactions

Contact between the clusters as well as contact between the clusters and the plate uses Hertz-type contact interactions, with a coefficient of friction of 0.5. The clusters have mass proportional damping of 10.0 s^{-1}.

Analysis steps

The total duration of the analysis is 1 second. The kinetic energy is monitored to ensure that it is small at the end of the analysis, indicating that the aggregates have reached an equilibrium state.

Run procedure

The job is executed in domain parallel mode. Only the parent particles are included in the original output database (.odb) file; therefore, visualizing the original output database displays only the parent particles. To visualize the clusters, you run the python script `createDEMcluster_model.py` (in the directory where the output database from the job execution is located) using the following command:

```
abq python createDEMcluster_model.py demclusterdrop.odb
```

The script creates a new output database with information for all the particles in the cluster. The script reads the output database file from the original job and generates a new output database by appending `_clst` to the original name. In this example, the original output database from the job execution is named `demclusterdrop.odb`; therefore, the name of the new output database create by the script is `demclusterdrop_clst.odb`. You can open the new output database in Abaqus/Viewer to visualize all the particles in the model.

Results and discussion

Figure 3 shows the final configuration of the particle clusters after being dropped onto the floor. The peak of the pile is about 200 mm above the floor. The final configuration depends on several factors such as the geometry and initial position of the clusters, the drop height, and the friction coefficients of the particle-particle and particle-plate contact interactions. You can explore the interlocking of particle clusters further by altering these parameters.

Files

demclusterdrop.inp

DEM nonspherical limestone aggregate drop.

createDEMcluster_model.py

Python script for creating a DEM cluster model.

Figures

Figure 1. Aggregate geometry and cluster geometry.

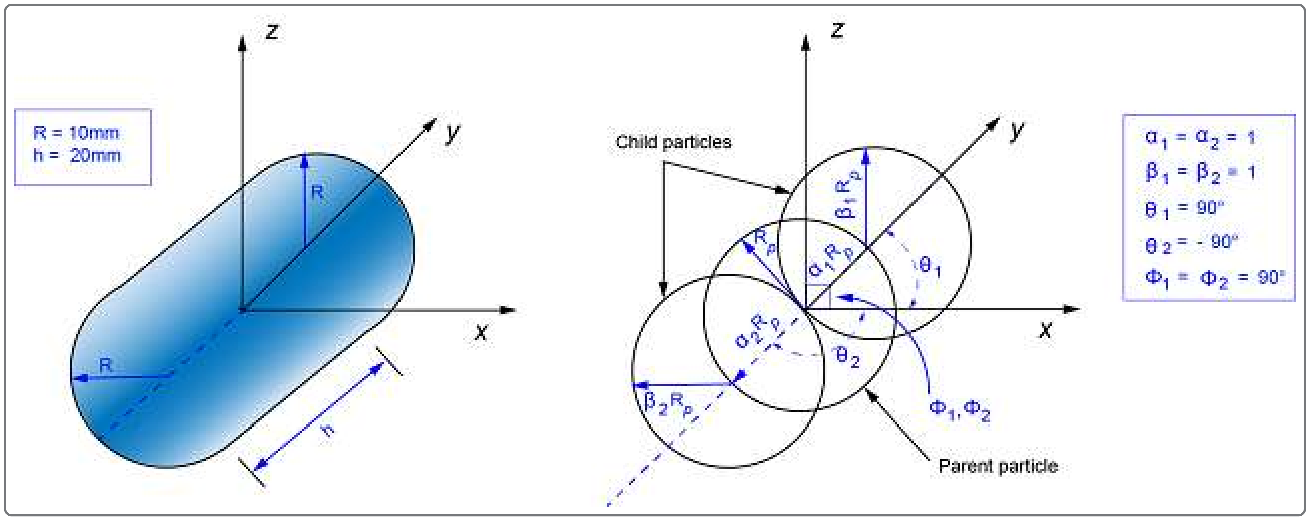

Figure 2. Initial configuration of the clusters.

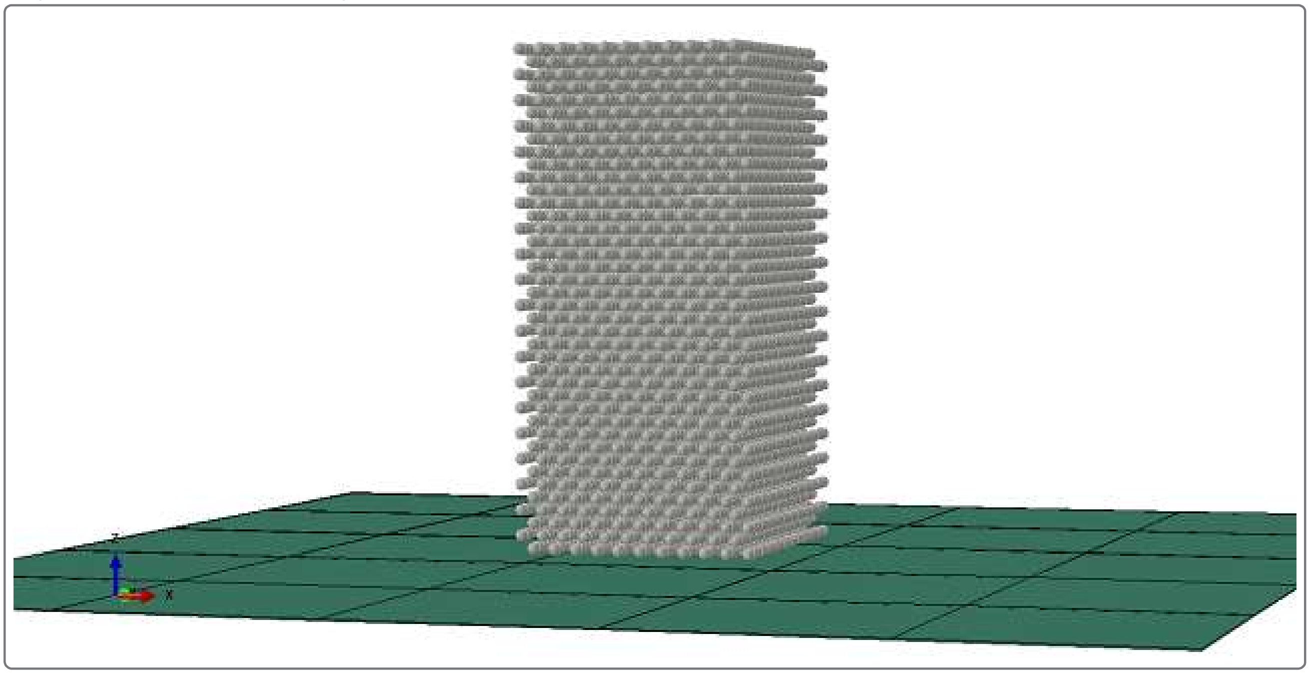

Figure 3. Final configuration of the clusters.