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REBOUND CHARACTERISTICS OF COMPLEX PARTICLE GEOMETRIES

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Abstract. Digital analysation method for the characterisation of rebound effects of non-spherical DEM-particles:

For the modelling of bulk material in DEM-simulations spherical particles are usually used. Due to their simple form and regarding the computational effort, such spherical particles offer an efficient modelling of bulk material with sufficient accuracy. However, spherical particles may lead to falsified results, especially in the case of highly non-spherical bulk materials (e.g. cylindrical pellets) or when certain effects are analysed in detail (e.g. rebound directions of particles). In general, the contact behaviour of complex particles is very different from the behaviour of idealised, spherical shaped particles. In this project a method was developed to analyse and compare the diverging rebound behaviours of different particle shapes: Particles with complex geometry are moved against a plane surface and the resulting rebound directions are detected. These directions are processed and the distinct rebound direction distribution characterises the analysed particle geometry. This method allows the analysation of rebound characteristics of bulk material concerning the scattering effects of the bulk. Subsequently, this allows a particle geometry definition in DEM-simulations in such a way, that a simple geometry (e.g. ellipsoids or cylinders) depicts the real bulk material (e.g. grain, hot briquetted iron etc.) in terms of rebound behaviour with high accuracy. Another approach is the modification of spherical particles by repositioning their centre of mass or by adjustment of their mass moment of inertia, so that the modified particle behaves like a particle with a more complex geometry. This method enables the analysation of rebound characteristics due to the particles' geometry

and allows the modelling of complex bulk materials with simplified digital geometries. Efficient simulations with complex particle behaviour are thus made possible.

1 INTRODUCTION

Nowadays the Discrete Element Method (DEM) has a wide area of application ranging from mining industry over agriculture all the way up to pharmaceutical industry. In all those fields the DEM can be used to predict the possible outcome of conveying systems or filling procedures. For simplicity and speed of the simulation a common approach is to use spherical particles. The choice is obvious as the sphere is a natural geometry that can be easily described in terms of contact detection and force calculation. However, there are aspects that could lead to falsified results as real bulk material will almost never have a perfectly spherical shape. [1]

Therefore, the usage of complex shaped particles was needed and became more popular or rather possible. There are four ways to form a complex particle in DEM simulations:

1. Multi-spheres: In this method many spheres with different sizes are stuck together to form a complex shape. The more spheres are used, the more accurate the real shape of the material can be represented as seen below in Figure 1 [2].

Figure 1: Multispherical Particles [3]

2. Primitive forms: Calculation-optimised common geometries (ellipsoids, cylinders, cubes etc.) offer an easy way to simulate material behaviour that is different to spheres. Some examples can be seen in Figure 2.

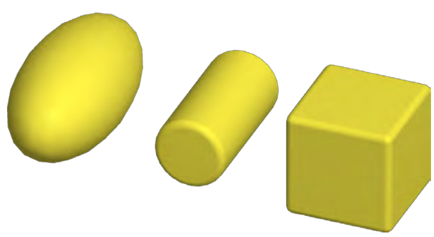

Figure 2: Primitive Forms [4]

3. Complex hybrid: Even more complex shapes can be realised if spheres and primitive shapes are combined to a new geometry. In Figure 3, a complex hybrid particle is shown. To achieve the geometry of a nail for example, a combination of two cylinders can be used.

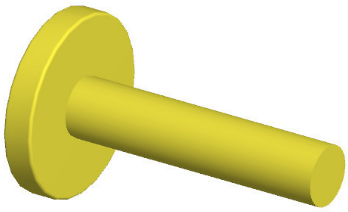

Figure 3: Compound/Complex-Hybrid Particle [4]

4. Fully complex particles: 3D-scanned particles or geometries designed in CAD-software can be implemented and used for simulation. In Figure 4, a designed flange can be seen that was imported and recalculated as a triangle mesh.

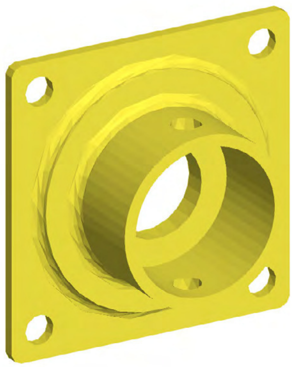

Figure 4: A flange as a DEM particle [4].

The calculation time and the computational power required to simulate more complex shapes rises significantly with the complexity of the particles.

There are a lot of differences how the particles behave if they are built up differently in the simulation [5]. For instance, if complex shaped particles are moved against a plane surface in a DEM simulation, they will rebound in a certain direction. This is due to the contact model for movement calculation that represents real particle behaviour. In the Hertz-Mindlin contact model it is built with a spring-damper system for each particle connected via a friction model [6]. As an example, the spring-damper-friction contact-system for an ellipsoid is shown in Figure 5 [7].

In Figure 6, the exact moment of contact of a particle with a part is shown for a sphere and an ellipsoid. For a sphere, the reaction force F will always be in a line with the gravitational force G. For ellipsoids this is not always the case. Depending on the

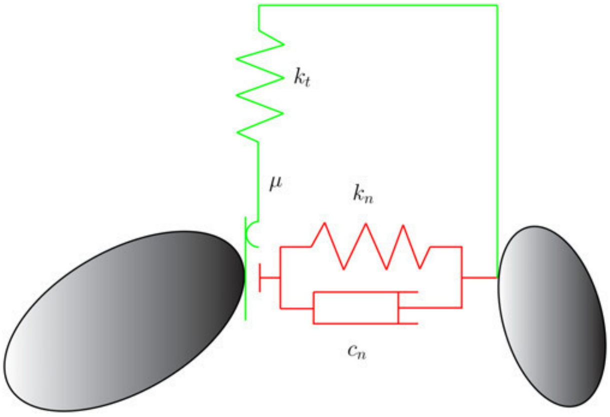

Figure 5: Mechanical contact system of two interacting ellipsoids [7]

distance r between the reaction force F and the gravitational force G of the particle, a torque momentum is initiated. Among other factors this leads to a change of rebound direction. This generated momentum of the particle has a strong influence on it's rebound behaviour. Friction between particle and surface is mandatory here (just as a tire of a car needs friction to move the car forward). That is why a strong deviation compared to spheres is expected for different geometries.

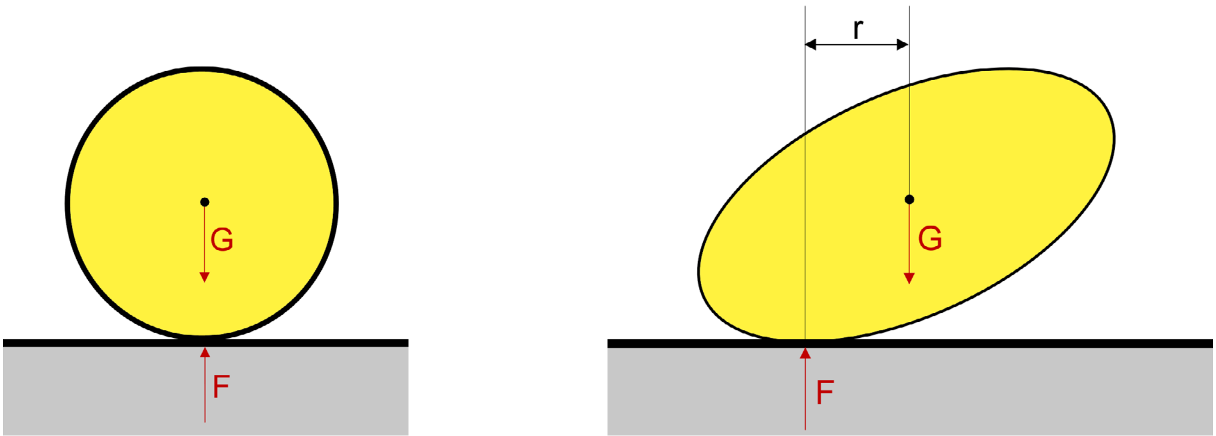

Figure 6: Generated momentum by the distance between centre of gravity and point of contact

2 Approach

The idea of this research project was to spotlight primitive forms and to determine how differently they behave compared to spheres by using the software *ThreeParticle/CAE* [4]. The focus in this project lies in the particle's rebound characteristics. As mentioned before, the entry angle of the falling particles is different to the exit angle after the rebound. To compare primitive forms to each other, shapes, that are similar to a sphere, were taken into consideration. The decision was made to examine cylinders and boxes with rounded edges as well as ellipsoids. Spheres with a dislocated centre of mass were also studied. To actually compare those shapes, they need to have the same size. Therefore, the volume of a sphere with a certain diameter was calculated and the other shapes were then formed with the same volume.

2.1 The Parameters

To compare different particle geometries, it is required, that all simulation parameters are identical for all analysed shapes. In order to achieve this, it is mandatory to find the right value for those parameters as several of them have a strong impact on the outcome.

The general material parameters (density, shear modulus and poisson's ratio) are all attributes that need to be set to a certain value for the simulation to work. It is common to set the value for the shear modulus smaller than the real material value. This enhances the simulation speed and still provides the needed accuracy, but in this case, it should not be too small. The reason: It strongly affects the rebound angle. If the value is too small, it becomes hard to distinguish a different rebound angle as almost all particles will rebound straight up again. One can imagine this behaviour by thinking about dropping a sharp-edged cube in the middle of a trampoline. No matter how different the cube is shaped compared to a sphere, it will not affect the rebound angle significantly.

For our research the Hertz-Mindlin contact model was chosen. In *ThreeParticle/CAE* [4] three parameters can be set for this model: Restitution, static friction and rolling friction. Restitution normally has a value between zero and one and it describes the energy that is conserved after a collision of a particle with a part or another particle. It is important that it is not equal to zero as a fully elastic impact is required. For friction this works the same way. The value for static friction needs to be above zero, otherwise the momentum generated by the impact of non-spherical particles will not lead to a change of the rebound direction. As for the shear modulus mentioned above static friction has a strong influence on the rebound angle and should be chosen wisely. Rolling friction plays a minor role and can be neglected in this test. If all other parameters in DEM simulations are the same for each analysed particle, the resulting rebound direction distribution of the test characterises those analysed shapes, which can be compared to others.

2.2 The Test

To test the rebound behaviour and to receive the final rebound direction distribution, a method was developed where the difference of the rebound can be seen directly. The test consists of a generation plane, a rebound plane and a half dome as visualised in Figure 7. The generation plane of the simulation was modelled as small as possible, but still large enough so every particle can be created, in order to minimise inaccuracy. Below this plane, one particle after another is created and given an initial speed. This way the particles are moved against the rebound plane with which they interact. After their contacty they move in a certain direction in a straight line as shown in Figure 8, as gravity is disabled in this simulation. For measuring, the half dome is made up by small cone shells. Each cone shell represents a one degree interval. Each particle will touch one cone shells of the half dome after their rebound. Here, every contact is counted for the corresponding cone shell. If the number of particles is high enough this leads to a rebound direction distribution for each analysed complex particle.

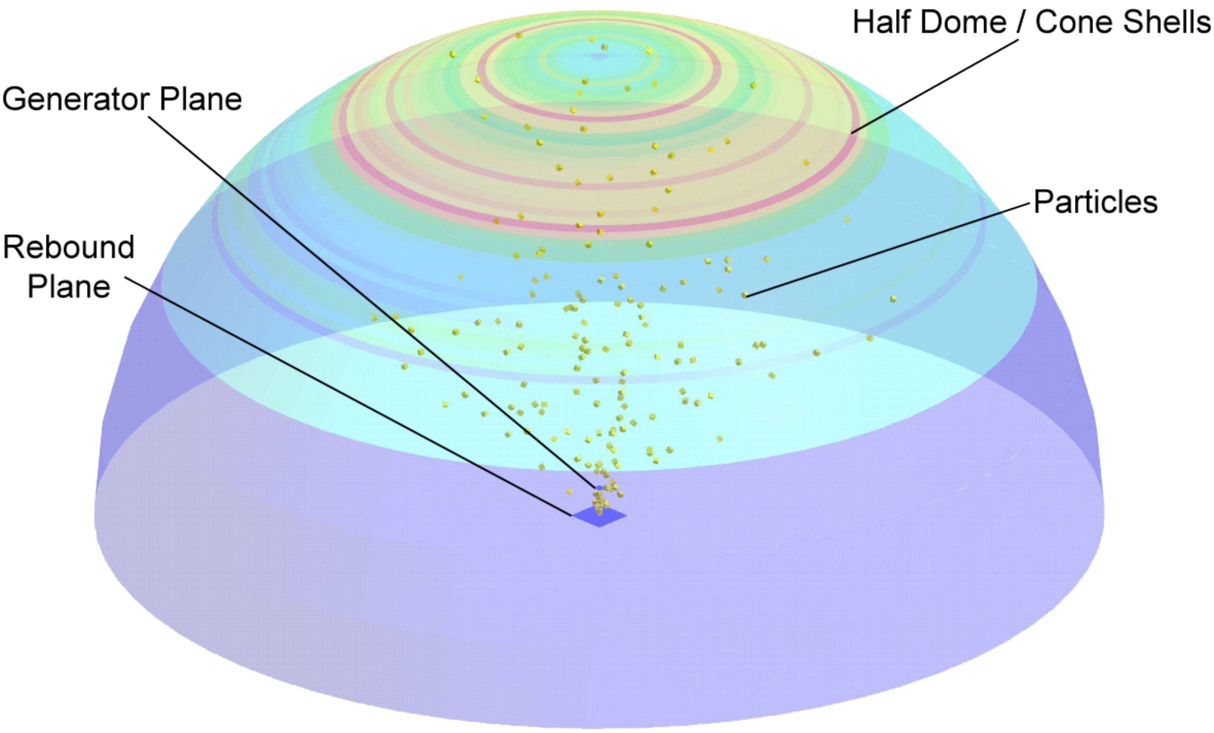

Figure 7: The test setup

3 CONCLUSION

A method was developed to receive characteristic rebound direction distributions for primitive forms of particles in DEM simulations. This way the deviation of the rebound direction compared to a spherical shaped particle can be analysed. After multiple different primitive forms have been examined, it is made possible to analyse differences in the rebound behaviour of various particle shapes. As primitive forms are relatively new to be used in common DEM software, this will be useful for the simulation of bulk material. A lot of minerals are nowadays pressed into cylindrical shapes also known as pellets or in pharmaceutical industries the ellipsoid or capsule shape are found all over the market. If precise results are required in DEM simulations it is needed to design complex particles and it is good to know in advance how they will influence the computed simulation results.

Another idea is to compare spheres with a dislocated centre of mass to primitive forms. The distance between the centre of volume and the centre of mass of a sphere can be adjusted to result in a distribution that is similar to the distribution of a complex shaped particle. The complex particle can then be exchanged in the simulation for a modified sphere. This will lead to faster simulations without neglecting complex particle behaviour.

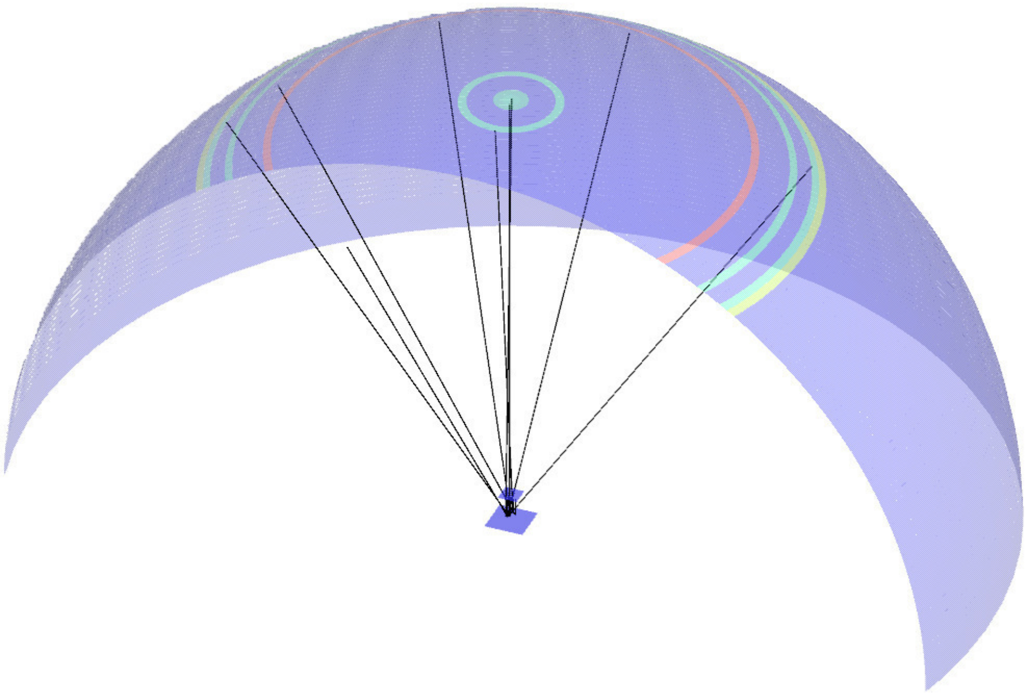

Figure 8: The streamlines of the particles

For future research, a more precise analysis method with the help of the built-in API (application programming interface) of *ThreeParticle/CAE* [4] will be developed to minimise inaccuracy as far as possible. It will then be possible to receive precise distributions for each particle and further influences of complex shaped particles in DEM simulations can be researched.

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