SPHERE PACKING FOR DISCRETE ELEMENT SIMULATION ON GID

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Abstract. *In the last years, the Discrete Element Method (DEM) became a very useful tool for the simulation of geomechanic and particle movement processes. The first step in a discrete element simulation is the discretization of the domain into a set of particles. The cost of generating a good cylindrical or spherical packing has resulted in a great number of approaches during the last years. A new algorithm is proposed for high density packing using a scheme which minimizes the distance between each particle. Using the support of a finite element mesh, less time is needed in order to achieve a low porosity configuration. In addition, a boundary constraint is introduced. The application of the same optimization scheme is used as a condition to force a good surface definition. The results obtained present a high efficiency for the generation of low porosity packing, achieving values smaller than 10% in 2D cases and 30% in 3D cases. This technique is implemented in GiD, where the creation of the new element type Circle (2D) and Sphere (3D) allow the generation of discrete element models. An extra support for the analysis of the generated mesh, as volumen, porosity or coordination number is created in order to obtain a better managment of the meshes.*

1 INTRODUCTION

In the last years, the discrete Element Method (DEM) became a very useful tool for the simulation of geomechanic and particle movement processes [1–4]. The technique requires the discretization of the media by a finite set of particles. The present work proposes an alternative technique for the generation of very dense particle distributions. The idea is to use a fast algorithm for an initial generation, like some of the ones presented previously and densify the package by an optimization algorithm. In particular, a finite element mesh based scheme is used.

2 THE ALGORITHM

The main idea of the method is to *improve* a given particle assembly in order to obtain a lower porosity configuration.

Given an initial particle distribution, a high porosity exists when the neighbouring particles are not in contact. The reduction of porosity condition can be written as a non-linear square problem where the function to be minimized is given by the distance between neighbouring particles of the original configuration. This allows the inclusion of boundary constraints to ensure a good reproduction of the boundaries, a feature which constitutes a mayor advantage in all the cases in which the friction between surfaces is important[4] .

2.1 Internal contacts

A low density initial assembly is assumed in order to define the existence of neighbouring particles without contact. The low density is produced by the void areas where the contacts are not achieved. A modified distance function is defined between all neighbouring particles, where the existence of the contact pair is introduced by a triangulation. In a local neighbourhood for one particle the distance function between particles i and j can be defined as

$$d_{ij} = \|\vec{x}_i - \vec{x}_j\|^2 - (r_i + r_j)^2 \tag{1}$$

where $\vec{x}_k$ is the coordinate center of the particle k and r_k its radius. The square of the values is used for the sake of simplicity, because a derivative function is required and the minimum of this modified distance is equivalent to the standard function.

In order to find the minimum of void areas or interstitial spaces, the function needs to be minimized for all the particles in the assembly. For that purpose, a global function is defined using a minimum square scheme, where the global function is written as

$$min \quad F = \sum_{i=1}^{m} \sum_{j=1}^{m} \delta_{ij} d_{ij}^2 \tag{2}$$

where δ_{ij} is a Kronecker delta function which defines the existence of the contact pair [i,j]. These connectivities are achieved by the edges of the triangulation over the initial assembly. The square of d_{ij} is used because the minimum of any contact pair is required, and the use of a linear system may cause some negative values in the radii of the particles.

The system can be now solved for an initial assembly, where the final compactation degree allows a very low porosity level. The convergence rate of the scheme depends on the initial configuration. A good result is however obtained in few iteration steps.

2.2 Treatment of boundaries

A boundary constraint or boundary condition is proposed with the same argument as in the previous section. A modified function of the distance between the contour of the geometry and the external particles is used in order to obtain a homogeneous contour in the external of the assembly. In the external zone of the domain it is possible to establish the distance between the particle i and some boundary line k as

$$R_{ik} = ||\vec{d_i}||^2 - r_i^2 \tag{3}$$

where $\vec{d_i}$ is the vector joining the center of the particle with the closest boundary point.

We will assume in the following that the algorithm is finite element mesh based. Hence only the inner nodes of the mesh are particles, while the outer nodes define the boundary mesh.

With the introduction of this new condition, a modified version of the equation (2) is written.

$$min \quad F = \sum_{j=1}^{n} \sum_{j=1}^{n} \delta_{ij} d_{ij}^2 + \sum_{i=1}^{n} \sum_{k=1}^{n} \delta'_{ik} R_{ik}^2 \tag{4}$$

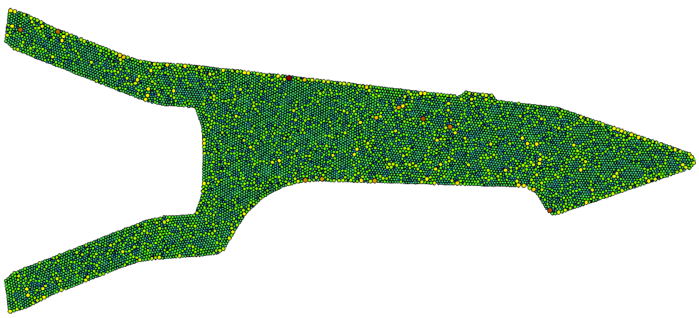
The resolution of this system for a set of particles is able to solve the density problem and a good boundary definition for the final configuration of the assembly.

2.3 Initial generation of the media

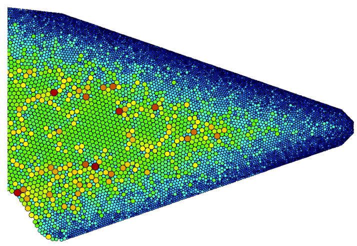
For the generation of the initial configuration, it is possible to use any algorithm proposed in the literature. However the finite element mesh based techniques offer better conditions for the algorithm proposed in this work. This is because very developed algorithms exist and the generation of complex geometries is achieved easily. One of the necessary considerations for the initial mesh is the structuration of the elements, because very regular elements produce a regular number of contacts for the different particles and a homogeneous package of particles is found. In order to safe the problem, an initial preprocess is made over the mesh, where random local displacements over the node position is used to generate a random configuration.

3 EXAMPLES

An example for a 2D generation with refinement is shown in Figure 1. An application



(a) Discretization with 23500 cylindrical particles.



(b) Detail of refined zone.

Figure 1: Tooth of excavation machine discretized with cylindric particles and refinement in the interaction surface.

example in 3D is shown in Figure 2. Similar to the 2D example, a tooth of an excavation machine is discretized with 25000 particles. A good result of the generation process can be observed. The final porosity in the example is 30.77%.

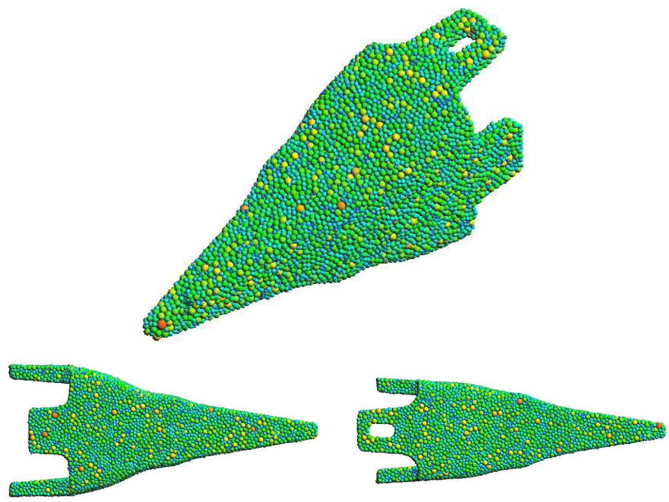


Figure 2: Tooth of excavation machine. 3D discretization.

4 GID SUPPORT OF CIRCLE AND SPHERE ELEMENTS

This algorithm has been implemented in the GiD kernel. New *Circle* and *Sphere* element type can be handled. Basic support features for this elements include drawing, selection, mesh generation, scripting access, postprocess, and element's quality.

5 CONCLUSION

- A new dense sphere particle packing algorithm has been presented.
- A boundary constraint is included in order to obtain a good surface definition, allowing the discretization of complex geometries.
- The comparison with other algorithms shows a good result for the porosity and coordination number, with a considerable speed.
- This technique is a good candidate for problems which require a high density packing.

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