DETERMINATION OF THE DISCRETE ELEMENT MODEL PARAMETERS OF GRANULAR MATERIALS

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Abstract

Engineers working on the field of agriculture, food- or pharmaceutical industry or in the architecture frequently met problems arising from the special properties of granular assemblies. The practicing engineer has to know how granular materials behave so as to be able to examine and control their mechanical behavior. The design cost of the processes can be greatly decreased if we are able to model properly the given mechanical phenomena.

From the mechanical point of view, two different type of material models can be established. The discrete element method (DEM) where the physical parameters of the interaction between the distinct grain particles (the so called micromechanical parameters) are modeled, and the continuum model, where the whole granular assembly is modeled as a continuum. At our Department and at the Institute there is an ongoing research on developing a method for determining the micro mechanical parameters of granular assemblies by carrying out measurements of the macro mechanical parameters and by modeling the same measurements using discrete element method.

Introduction

Most of the raw materials and crops in agriculture are treated and stored in form of granulates. The prognosis of the mechanical interaction between the particulate material and tools or containers during the various procedures is absolute necessity in every aspect of efficient agricultural processes. The practicing engineer has to know how granular materials behave so as to be able to examine and control their mechanical behaviour. The design cost of the processes can be greatly decreased if we are able to model properly the given mechanical phenomena. The mechanics of granular assemblies is one of the most complicated area of engineering mechanics, because the description of the behaviour of large number of particulate materials is a quite complex scientific problem.

The Discrete Element Method (DEM) is a fairly new proceeding to model the mechanical properties of bulk materials. By the use of DEM, the model problem is solved by applying and solving the equation of motion on each singular particle of the bulk material assembly. The discrete element model facilitates to trace the contact forces between the particles of the bulk material. From this we can get information also to determine the damage of the components of agricultural product [Fenyvesi 2002, 2003]. The wide range of applicability of DEM is detained by the fact that we have to determine the values of different micromechanical properties related to the interaction between the individual particles in order to model the mechanical process. The method of this micromechanical parameter determination is often called as calibration procedure. In this paper, we use oedometric test to calibrate the micromechanical parameters of sunflower seeds.

Strength characteristics measurement by odometer

The measurements had been carried out in the material testing laboratory of the Hungarian Institute of Agricultural Engineering. For the strength characteristics measurement an Instron 5581 universal material testing equipment was used (Fig. 1). This equipment is able to load 50 kN uniaxial tension and pressure. The corresponding crosshead displacement size is 2 meter. The cross-head speed range could be set between 0.001mm/min and 1000 mm/min (speed accuracy is 1%, the position accuracy is +/−0.02mm). The equipment has three certified load cells which have 0.5% accuracy of the measured value in three different load ranges: from 0.025 to 5 N, 5-500 N and from 500 to 50,000 N. The equipment is controlled by a computer, the electronic sampling frequency is 500 Hz and the A/D converter is 32 bits.

Figure 1. The Instron 5581 materials testing equipment

For the investigations by odometer we produced a 80 mm high, 100 and a 200 mm diameter steel tanks with an inserted plunger in the upper part. By this plunger we loaded various crops (Fig. 2).

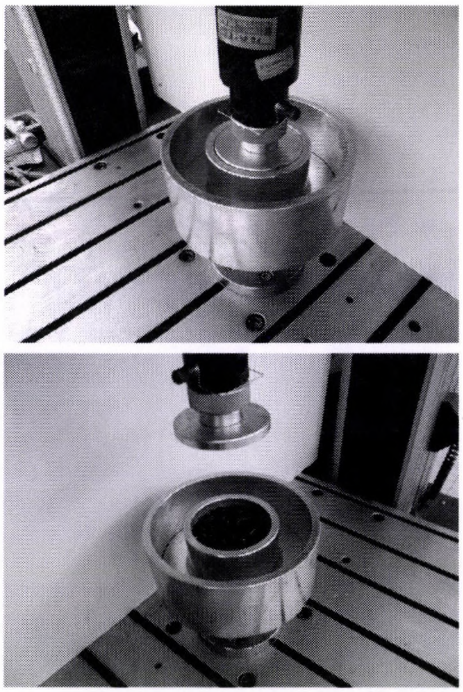

Figure 2. The steel tank with an inserted plunger

The machine settings were as follows:

– Pre-load: 100N
corresponding crosshead displacement was 25 mm/min,

– Load: till 30000 N
corresponding crosshead displacement was 500 mm/min.

For mass of the investigated crops we used a Kern-572 laboratory balance with 0.1 g precision. Mass of the samples were x grams. For the moisture content determination a Dicky John made by GAC ® 2100 type device was used. The Fig. 3. shows as an example the results of the sunflower investigation by odometer.

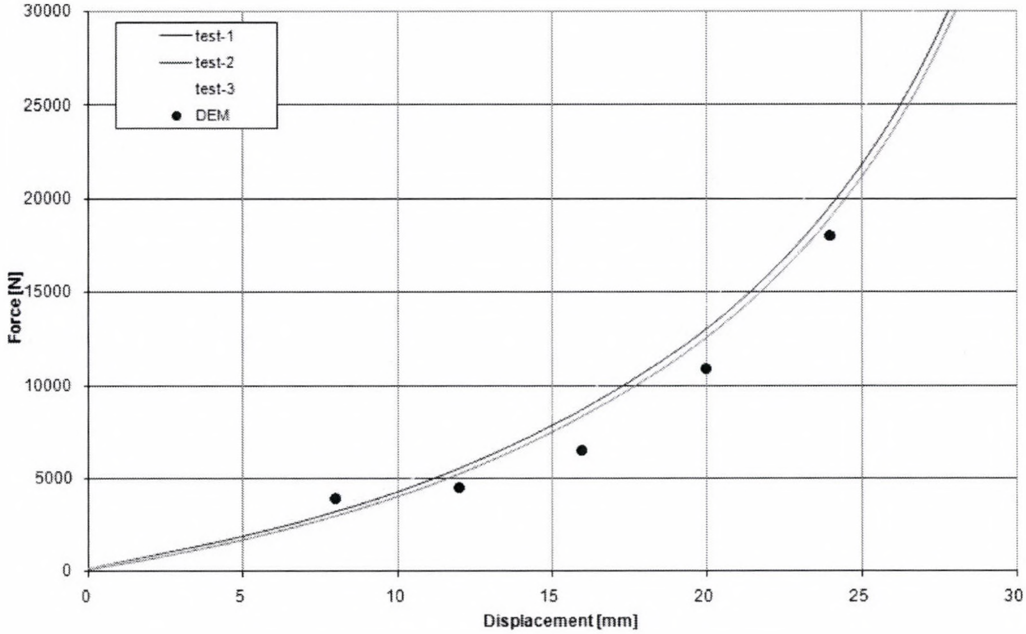

Figure 3. Results of the sunflower investigation

Discrete element simulation

The Discrete Element Method (DEM) is a fairly new proceeding to model the mechanical properties of bulk materials. By the use of DEM, the model problem is solved by applying and solving the equation of motion on each singular particle of the bulk material assembly.

For the simulations we used the EDEM discrete element software.

For the discrete-element simulation we created the model of the odometer (Fig. 4). Hertz-Mindlin contact model was used for calculation of the contact forces between the particles. In the Hertz-Mindlin contact model the normal force between two particles contact can be determined by the following relationship:

$$F_N = \frac{4}{3} E \sqrt{R} \delta_n^{\frac{3}{2}}$$

where E is the elastic modulus of particle, R is the radius of curvature and δ_n the indentation in the contact point. While running the calculations we have to use a F_d^D damping factor to reduce oscillations of the numerical calculations. The value:

$$\left|F_n^D\right| = 2\sqrt{\frac{5}{6}} \beta \sqrt{s_n m} v_{rel}$$

where m is the mass of the particle, and v_{rel} is the normal component of the relative velocity,

$$\beta = \frac{\ln c_r}{\sqrt{\ln^2 c_r + \pi^2}}$$

s_n is the normal stiffness of the compression in the contact point of the granular material. During the simulation the used time step has a great impact on the stability of the numerical model. When the value of the time step is too big it may cause disintegration of the model because of the program calculated big change of compressive strength between two steps. That's why we selected for the simulation the 25% of the Rayleigh-type time step:

$$T = 0,25 T_R = 0,25 (0.163 \nu + 0,8766)^{-1} \pi R \left(\frac{\rho}{G}\right)^{\frac{1}{2}}$$

Table 1. Mechanical properties of the particles

Shear elasticity modulus	$G = \frac{E}{2(1+\nu)} = 11$ MPa
Poisson coefficient	$\nu = 0.4$
Density	$\rho = 759$ kgm^{-3}
Collision coefficient	$c_r = 0.6$
Friction coefficient	$\mu_s = 0.6$
Rolling resistance coefficient	$\mu_r = 0.01$

As first simulation result approximate discrete-element mechanical parameters of the sunflowers were determined. We started the discrete element simulation to study the odometer investigations based on the data of Table 1 and particle shape Fig. 5. The shape of particle – according to our view – is not necessary to be exactly equal to the original shape of the particle. It is sufficient to use different shape from the spherical symmetry. The results of the calculation are indicated by points in the Fig. 3. Comparing the results of the measurement and the results of the simulations in the diagram the differences are acceptable at higher compression values. Therefore we can say that the data of mechanical properties of the particles in Table 1. ensure adequate accuracy for the discrete element model of sunflower seeds.

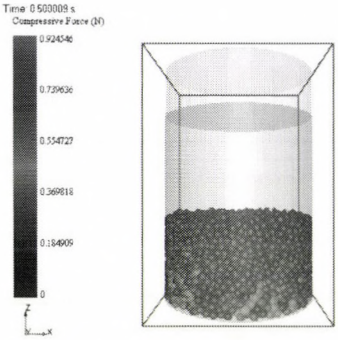

Figure 4. Discrete element model of the odometer

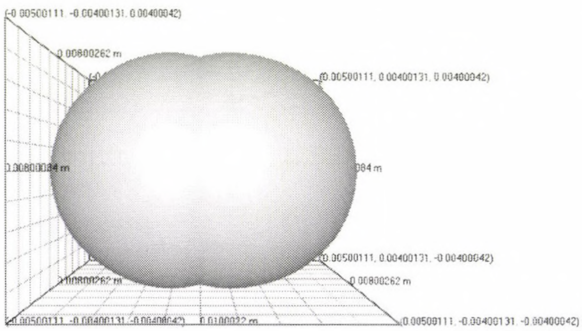

Figure 5. Model of a single particle

Results and further work

A relatively new method used for modelling the mechanical behaviour of granular assemblies during drying processes is the so called discrete element modelling technique. In this model we describe the granular assembly as the collection of large number of small rigid bodies, and the modelling process of the assemblies' behaviour is based on solving the equations of motion of this large number of particles directly. The question that arises from the practical use is how we can determine the parameters which affect the interaction between the particles: the coefficient of static- and rolling friction, coefficient of restitution, Young modulus and Poisson's ratio of a given (in some cases very small) particle.

We started to develop a procedure based on measurement and numerical simulation of the measurement for determination of micro-mechanical parameters of agricultural grains by discrete element model. The first step in the procedure is the bulk material measurements by odometer. We carried out the laboratory investigations by wheat, corn, barley and sunflower seeds. We developed discrete element model for odometer measurements and we determined the micro-mechanical parameters of sunflower seeds (Table 1).

Thereafter, we will carry out the discrete-element calculations in case of other three types of grain. We will investigate by sensitivity analysis the obtained parameter results of the model. After the shear test [Balássy, 1993] measurement, we will also verify the adequacy of the parameters by comparison of the simulated shear test results – where the micromechanical parameters were used as the result of the odometer investigation – and the obtained results of the shear test measurements.

The method will be applied later for determining the velocity distribution of granular materials moving in mass flow driers.

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