# DETERMINATION OF GRANULAR ASSEMBLIES' DISCRETE ELEMENT MATERIAL PARAMETERS BY MODELLING THE STANDARD SHEAR TEST

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**Abstract:** Soil and agricultural products interact with the tools and equipment used to manipulate and store them. This interaction causes the load of the tools and of the agricultural product. The practicing engineer has to know how these types of materials behave so as to be able to examine and control their mechanical behaviour. To fulfil this aim we have to find a general model of these materials and apply this to the specific cases. A relatively new model of granular assemblies is the so called discrete element based model. 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. The direct measurement of these quantities is of course impossible for really small particles. We developed a new method based on performing the standard shear test of the given materials and by modelling the shear test using discrete element method. If the discrete element parameters of the numerical model are properly set, the output data coming from the measurement will be in good agreement with the data coming from the discrete element model.

**Keywords:** mechanics of granular materials, discrete element method, shear test

## 1 INTRODUCTION

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 most important properties determining their mechanical behaviour are their material- and failure models.

From the mechanical point of view, two different type of material model can be established: the so called discrete element model, where the physical parameters of the interaction between the distinct grain particles (the so called micromechanical parameters) are modelled, and the continuum model, where the whole granular assembly is modelled as a continuum. The difficulty of the mechanical modelling arises from the problem that the continuum model's (here called as macromechanical) parameters can be determined by measurements developed long ago, but the determination of the micromechanical parameters is difficult and sometimes impossible.

At the department of Mechanics and Engineering Design of Szent István University and at the Hungarian Institute of agricultural Engineering we developed a method for determining the micro mechanical parameters of granular assemblies by carrying out measurements of the macromechanical parameters and by modelling the same measurements using discrete element method.

By presenting a given granular assemblies shear test, we demonstrate the determination of the micromechanical properties of that assembly. The micromechanical parameters of the assembly are determined by modelling the shear test using discrete element method. By changing the micromechanical parameters in the discrete element method it is possible to get different shear diagrams. If the discrete element parameters of the numerical model are properly set, the output data coming from the measurement will be in good agreement with the data coming from the discrete element model. We suppose that the micromechanical parameters describing the shear process with good accuracy are the micromechanical parameters of the granular assembly, and can be used for the discrete element modelling of the given type of granular material.

## 2 THE DISCRETE ELEMENT METHOD

Granular material is a conglomeration of discrete solid, macroscopic particles. From purely physical point of view, the best way of the modelling of such kind of material is solving the equation of motion for all of the particles assembled, taking into account the collisions and other interactions between them and the other bodies (such as containers, tools). Of course, from the practical point of view, this is impossible for large number of particles. Or it is better to say this has been impossible for all cases until recent years. Nowadays, for suitable number of particles, such kind of modelling is possible.

Figure 1. Granular materials

The method used for this type of modelling is the so called discrete (or distinct) element method. Discrete element method (DEM) is the name of a mathematical method used for describing the kinematical behaviour of particles. As defined by Cundall [1], discrete element methods allow finite displacement, rotation and separation of elements, and new particle contacts are recognized algorithmically as the simulation proceeds.

After Cundall's pioneering work, the computational backgrounds of DEM based research were established. Even the strong hardware needs of such computing can be satisfied for modest problems. Modest means here sufficient number of particles to model real engineering problems arising from the industry. The difficulties of such kind of modelling are the determination of micromechanical parameters influencing the interaction between the different particles. These parameters to be determined prior to starting the DEM modelling are:

1. The shear modulus $(G)$ of the particles.
2. Poisson's ratio $(\upsilon)$ of the individual particles.
3. Density $(\rho)$ of the particle.
4. Coefficient of restitution $C_R$.
5. Coefficient of static friction $\mu_s$.
6. Coefficient of rolling friction $\mu_r$.
7. Cohesive energy density $C_e$.

The method of finding these parameters is called as the calibration of DEM model. The calibration process is based ono observing and measuring the behaviour of the granular material in given circumstances, and on modeling the same process using DEM. By comparing the results of experiments and their models, the micromechanical parameters can be determined. Our calibration process is based on the so called standard shear test.

## 3 THE STANDARD SHEAR TEST

The standard shear testing technique for particulate solids is based on the so called Jenike shear cell [2]. The Jenike Shear Cell (fig. 2.) consists [3] of a base (1) shear ring (2) and shear lid (3), the latter having a bracket (4) and pin (5). Before shear the ring is placed in an offset position and a vertical force $F_v$ is applied to the lid and hence to the particulate solid within the cell by means of a weight hanger (6) and weights (7).

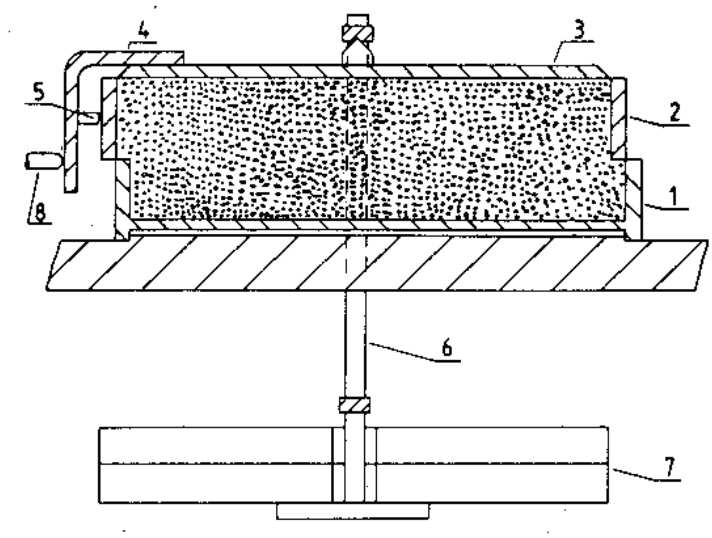


Figure 2. Jenike shear cell [4]

A horizontal force is applied to the bracket by a mechanically driven measuring stem (8) which is driven forwards at a steady rate of 1-3 mm/min. This stem is attached to the drive system through a force transducer which measures the shear force $F_s$. During the shear operation the shear ring moves from the original offset position to the opposite. During shear a shear zoned develops inside the sample, and in this way the shear force vs. time plot can be transformed to a shear force – shear strain plot. Using Jenike shear cell, the friction between the granular material and the container wall (the so called wall friction) also can be determined [3].

Based on the description found in the literature [4] we developed an automatic shear device making the same shear process described above (fig. 3.).

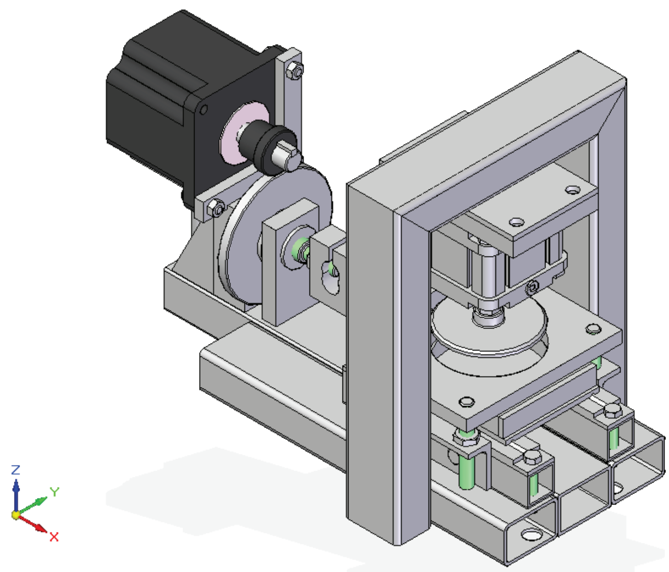


Figure 3. Automatic shear testing device

By using this automatic shear testing device, we determined the yield loci (the envelope of the Mohr circles corresponding the failure at given normal load) of cement powder for demonstrating the usability of our calibration method. First we made critically consolidated samples of the cement powder, critically consolidated means that the shear force – shearing distance diagram has no local maximum point, but saturates within the shearing distance of the cell. A particulate solid is critically consolidated with respect to the state of stress applied, when it yields without change in bulk density at a constant state of stress [4].

By pre-shearing the material sample using the compressive force corresponding to critically consolidated sample of cement, then lowering the compressive force successively to smaller normal forces (fig. 4.), we made the points of the yield loci for cement powder. Using linear approximation, we determined the yield line of the given powder by fitting a line to points determined by measurements (fig. 6.).

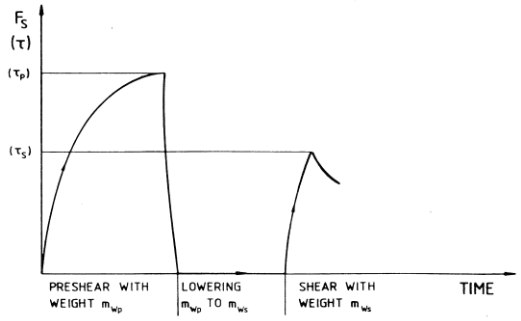


Figure 4. Preshear, lowering and shear [3]

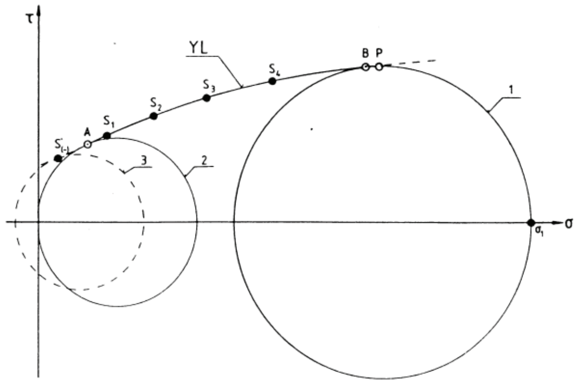


Figure 5. Yield loci

## 4 DEM MODEL OF THE STANDARD SHEAR TEST

By using commercial DEM software, we created a simple shear cell model. The model consisted of two cylinders (having the same size as the standard Jenike cell), an upper plate and a plane dividing these two. We filled the cylinders with spherical particles having radius randomly distributed radiuses varying around $r = 0.003$m with a variance $\pm 0,0005$m (in DEM models, the particle sizes must not be inevitably the same as the sizes of the real particles [5]). The first phase of modelling was the filling of the cylinders with granular materials, then a pre-compression phase followed the filling. The pre-compression was made by the upper plate, as it was forced to move downwards until pressure on it resulted the vertical force needed to reach critically consolidated sample in the virtual tester.

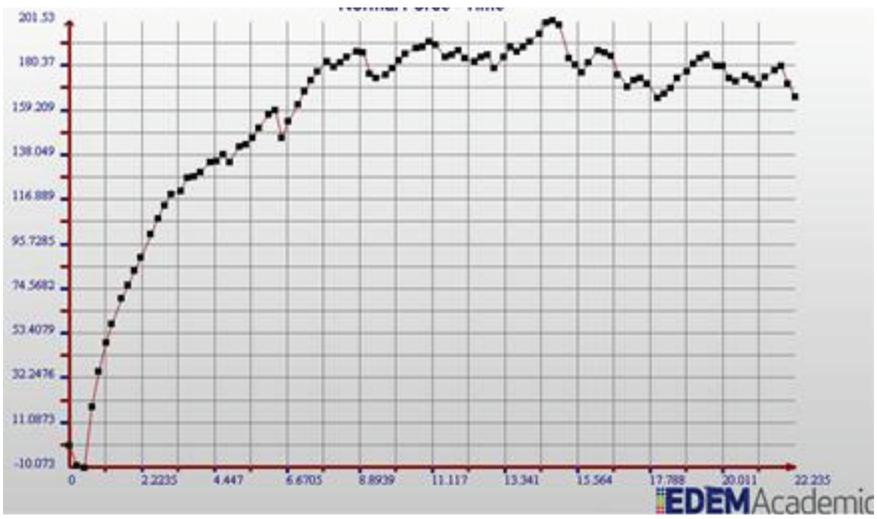


Figure 6. Shear force – time diagram from the DEM model, critically consolidated sample

After reaching critically consolidated state of the sample, the upper cylinder has started to move in the horizontal direction, modelling the shear process. From the pressure arising from the particles in the cylinder, the vertical force acting on the cylinder wall was determined.

By successive modelling of the shear process with DEM using different micromechanical parameters we managed to get yield loci from the "virtual" shear test being in a good match with the yield line determined by measurements (fig. 7.).

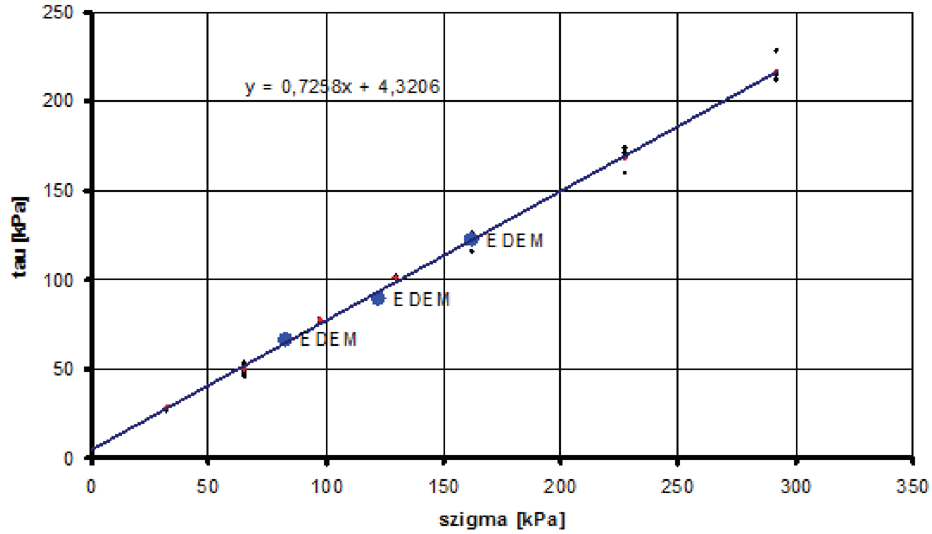


Figure 7. Yield loci in linear case from measurements, and yield points from DEM model

On fig. 7 small black dots are the measured yield points of cement powder, red dots denote the average values and blue dots correspond to the yield loci from the virtual DEM model of the given powder. The micromechanical parameters corresponding to the model were: 15000 $Jm^{-3}$ cohesion energy density, 0.25 as Poisson's ratio, $10^8$ Pa shear modulus, 3000 $kgm^{-3}$ density, 0.5 coefficient of restitution, 0.001 coefficient of rolling friction and 0.5 static friction coefficient.

By using the same method described above, the determination of micromechanical parameters is possible for any kind of granular materials.

## 5 CONCLUSIONS

We developed a method for determining the micro mechanical parameters of granular assemblies by carrying out measurements of the macromechanical parameters and by modelling the same measurements using discrete element method. Our calibration process is based on measuring the failure properties of the granular material during standard shear test. We demonstrated the usefullness of this method by measuring the failure properties of cement powder, and by doing the same using the virtual discrete element shear tester.

Further question is arising from these preliminary results as we do not know, wheter these values of micromechanical parameters are unique i.e. are there other set of values for the micro parameters resulting the same failure line during DEM shear tests? Are the results good for the practice meaning wheter using these values as micro parameters for modeling other mechanical processes give results beeing in good agreement with the results of measurements?

For finding the ansver for these questions, we plan to execute sensitivity inspections for the data arising from the shear model, and to do triaxial and oedometric tests on the same material samples and compare them against their discrete element model based on the micromechanical paramaters determined by the dicrete element shear test.

## 6 NOMENCLATURE

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| $G$ | shear modulus of the particle | $Nm^{-2}$ |
| $\upsilon$ | Poisson's ratio of the particle | - |
| $\varrho$ | density of the particle | $kgm^{-3}$ |
| $C_R$ | coefficient of restitution | - |
| $\mu_s$ | coefficient of static friction | - |
| $\mu_r$ | coefficient of rolling friction | - |
| $C_e.$ | cohesive energy density | $Jm^{-3}$ |
| $F_v$ | vertical force | N |
| $F_s$ | shear force | N |
| $r$ | perticle radius | m |

## 7 ACKNOWLEDGEMENTS

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