2D DEM SIMULATION OF THE SOIL- TOOL INTERACTION IN COHESIVE SOIL

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Abstract

The Numerical Model Systems are so modern nowadays. It means, that they can show under progress very similar physical phenomenas. To using a well built model is a useful and cost efficient method to develop the agricultural machines. In the agricultural point of view the contact or the interaction between the soil -tool and plant are very common. The optimization of the soil cutting is a kind of tool geometry design process. In these task we can validating the tool tillage method with qualitative and quantitative mode, because we can measure the work forces and can check the soil structure before and after the tillage method. The soil cluster quality or the porosity changing are so important and its dependences on the tillage speed and the tool geometry. To work cost efficiency is quite important in these days when the fuel and other equipments and man power prices are so expensive and the market competition is increasing.

Keywords

Soil, Cultivator, DEM, Modeling, 3D, Soil Bin, Forces,

Introduction

Computer simulations using Distinct Element Method (DEM) have been carried out to investigate the effect of cohesion on the flowability of polydisperse particulate systems (Tamás and Jóri 2007).

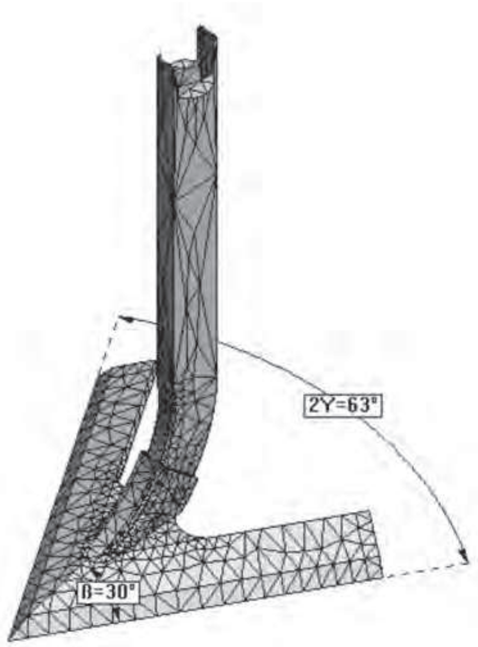

Figure 1. The Sweep-Tool geometry (2γ=63°, β=30°)

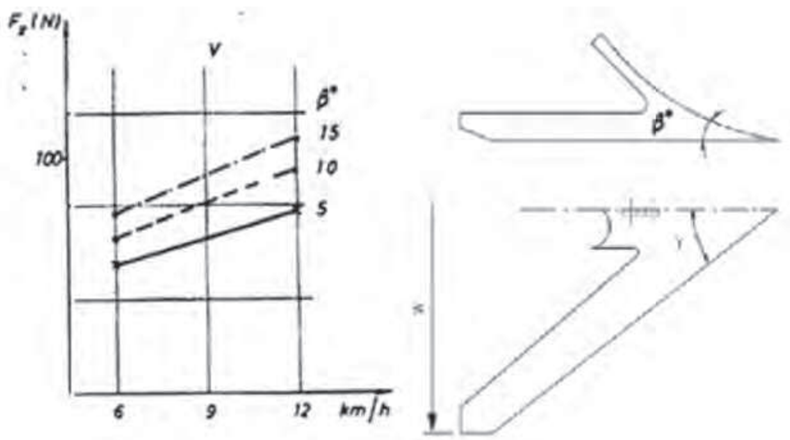

Figure 2. The draft force of the Tool vs. ß angle and the speed (SITKEI 1967)

The optimization of the soil cutting is a kind of tool geometry design process. In these task we can validating the tool tillage method with qualitative and quantitative mode, because we can measure the work forces and can check the soil structure before and after the soil- tool interaction. The soil cluster quality or the porosity changing are so important and it's dependences on the tillage speed and the tool geometry.

In this paper we introduce the most important process in the DEM that the synthetization of the real and artificial soil. There are many skepticists in face this field of science, that means they can not trust in the material models. We show the Sher Box Test, that sample (sand) got from the soil bin with the real physical properties. The other sample is on the computer and measured on Biaxial Test. The discrete balls, that bonded contacts representing the soil micro structure can be the most similar with the real soil. In the mechanical definition we used two values: the cohesion and the internal friction angle, that results of the Mohr- Coulomb criterion. In our works we used the PFC 2D DEM Code versatilities and efforts.

Materials and methods

DEM is a discontinuous numerical method based on molecular dynamics. It was developed and applied for analyzing rock mechanics by Cundall in 1971. The soil which is cut or separated by soil engaging components is much more discrete, therefore DEM is an ideal method to analyze large discontinuous deformations of soil. Cohesive soils are very common in agricultural operations and constructions (Asaf, Z., D. Rubinstein and I. Shmulevich 2007). The analysis of the dynamic mechanical behavior of cohesive soils subjected to external forces is very important in designing and optimizing the tillage tools. Cohesive soil contains water and the presence of water can produce cohesion between soil particles, which makes the mechanical structure of these soils much more complex (Cundall, Hart 1992). In order to simulate and analyze the mechanical behavior of cohesive soil accurately, it is necessary to establish a DEM mechanical model of cohesive soil by considering the effects of water on the mechanical behavior of cohesive soil. We could simulate this cohesion in the PFC2D Discrete Element Program, because it allows particles to be bonded together at contacts and with the virtual and real soil sample biaxial tests we can define the appropriate values.

DEM with the Parallel-Bond

PFC2D allows particles to be bonded together at contacts by employing the parallel-bond model. The parallel-bond model describes the constitutive behavior of a finite-sized piece of cohesive material deposited between two particles. The parallel bonds establish an elastic interaction between particles that act in parallel with the slip model described above. The existence of a parallel bond does not preclude the possibility of slip. Parallel bonds can transmit both forces and moments between particles, therefore, parallel bonds may contribute to the resultant force and moment acting on the two bonded particles.

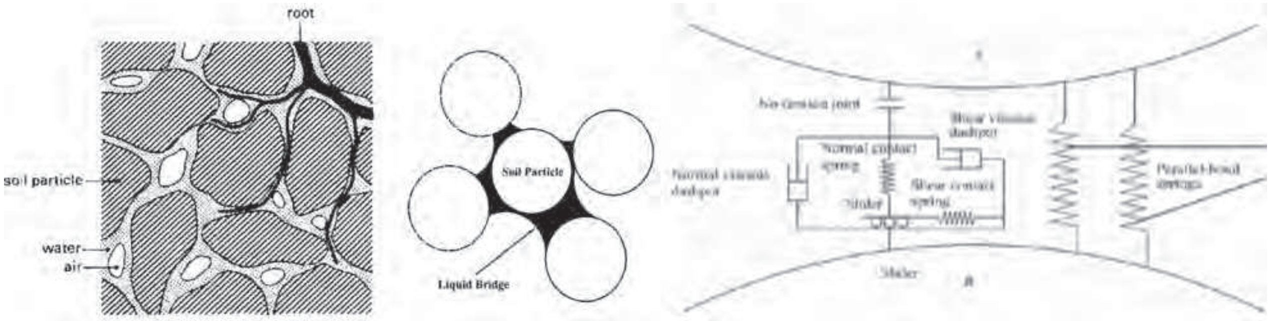

Figure 3. The microproperties of the soil, the liquid bridges, and the parallel-bond model (PFC2D Particle Flow Code in 2 Dimensions User's Guide 2002)

After the creation of a parallel bond, relative motion at the contact causes a force and a moment to develop with the bond material as a result of the parallel-bond stiffness. This force and moment act on the two bonded particles and can be related to maximum normal stress rmax and maximum shear stress smax acting within the bond material at the bond periphery. If either of these maximum stresses exceeds its corresponding normal strength and shear strength, the parallel bond breaks. If the parallel-bond model is used in the simulation. Although the configurations of the liquid bridges between cohesive soil particles change during the moving of soil particles, the effects of the deformations on the capillary and the dynamic viscous forces are ignored because of the above characteristic of the parallel bond. The capillary and the dynamic viscous forces are assumed to be influenced only by the parallel-bond forces. The parallel bonds produce the resultant force and the moment. (Bojtár, I., and K. Bagi 1989).

Description of the synthetic material

Most published work in the field of flowability and shear behaviour of powders is experimental. However, in experiments the measurements are usually made only from the boundaries of the assemblies as any effort to probe the internal state of the assembly might interfere with the behaviour of the particles. In contrast, the use of computer simulation allows the probing of the internal behaviour of particulate assemblies under mechanical loading. Therefore, the analysis of the flowability and shear behaviour of powders using computer simulation is attracting increasing attention recently.

In this biaxial test, a parallel bonded fine-resolution specimen was generated. The specimen has a height of 63.4 mm and a width of 31.7 mm and have uniform particle size distributions bounded by Rmin and Rmax, with Rmax = 1.66 Rmin (We can define the soil type with the particles distribution). We shouldn't define the value of R, because in the test we measure only a part of the full material (soil).

A strength envelope (peak strength versus confining pressure) was obtained by subjecting both rectangular specimens to a set of biaxial tests at confining pressures of 0, 1, 4, 10, 20, 30, 40 x105Pa.

During the biaxial test, the wall normal stiffnesses are set and the platen velocity is adjusted to reach a final value of 0.05 m/s in a sequence of 10 stages over a total of 400 cycles.

Table 1. Model parameters

Parameter in DEM	Value
Bulk density (kg/m^3)	1850
Particle shape	Ball
Normal spring coefficient (K_n) [N/m]	1,00E+07
Tangential spring constant (K_s) [N/m]	1,00E+07
Coulomb damping (μ_g)	0,3
Friction coefficient between particles (μ)	0,5
damp viscous normal [Ns/m]	0,7
damp viscous shear [Ns/m]	0,7
Particle radius distribution [mm]	23,44-39,07
Friction coefficient between particle and the sweep tool	0,6
Void ratio	0,4595
Parallel-Bond (heavy soil) (Result of the sinthezis)	
pb_rad	1
pb_kn (N/m)	2,00E+03
pb_ks (N/m)	2,00E+05
pb_nstren (Pa/m)	1,00E+06
pb_sstren (Pa/m)	1,00E+03
Parallel-Bond (loose soil)	
pb_rad	1,0
pb_kn (N/m)	2,00E+03
pb_ks (N/m)	2,00E+05
pb_nstren (Pa/m)	1,00E+05
pb_sstren (Pa/m)	1,00E+02
Time step of the calculation (Δt) (s)	4.0 ×10E5

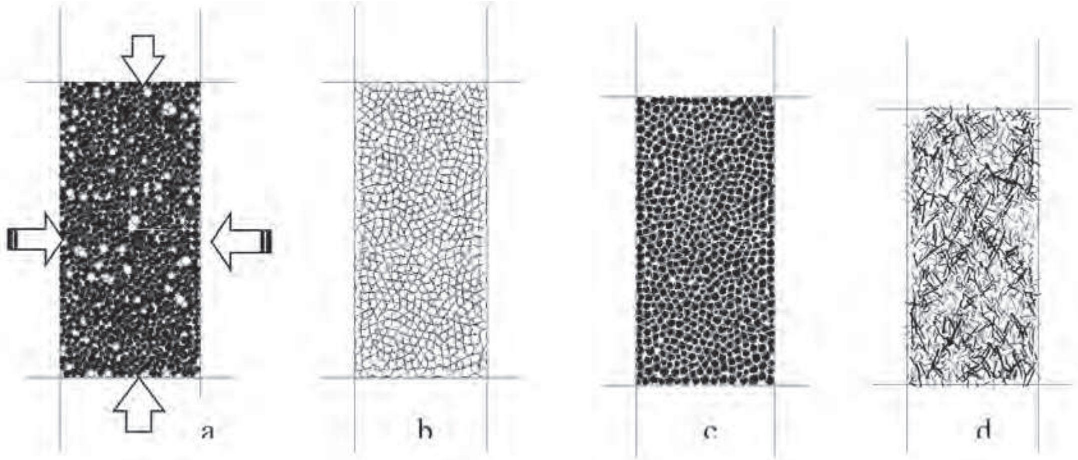

Figure 4. The specimen (a) vertical and confining stress, (b) contact structure, (c) parallel bonds between particles (white lines), (d) parallel bonds with normal and shear forces, when acting the vertical forces under the biaxial test.

Using the results of the biaxial test (the peak strength and confining stress) we defined the Mohr's circles. Touching the circles we drew the Coulomb line. The angle of the line and the x axis we defined the internal friction angle. The intersection of the Coulomb line and the y-axis we defined the cohesion. As we can see on the Figure 5. the cohesion is 51 kPa and the internal friction angle is 27°. This soil mechanics property following the real biaxial tests is a kind of loamy clay. We can validate these tests with the shear box test results and we can define the same material properties. With this process we can harmonize the real and the numerical methods. But in these test we used only the virtual aspect.

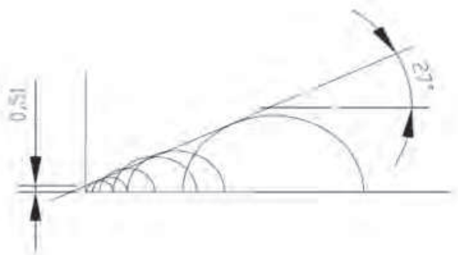

Figure 5. Mohr's circles, that define the cohesion and the internal friction angle. ($C=0{,}51x10^5Pa, \Phi=27°$)

Table 2. The results of the biaxial test

SPECIMEN		Results of Biaxial Tests
x: pack	y: Pc	sig_f
	($x10^5Pa$)	($x10^5Pa$)
1	1	7,59
1	4	20,56
1	10	34,07
1	20	61,97
1	30	90,82
1	40	118,95

We can see on the Table 2. the resulted peak strengh (sig_f) dependence of the confining pressure (Pc). With these results we can draw the Mohr's circles, thats tangential line define the cohesion and the internal friction angle. In our research these two soil parameters are enough to define the material.

Table 3. Soil mechanical values according to Schilling.

Soil Type	Cohesion (KPa)	Internal friction angle °	Friction modulus
Sand	0-10	37-34°	0,67-0,73
Sandy silt	10-25	35-32°	0,625-0,70
Silt	25-40	32-28°	0,53-0,625
Heavy silt	40,-60	28-25°	0,466-0,53
Clay	60-100	25-20°	0,37-0,466

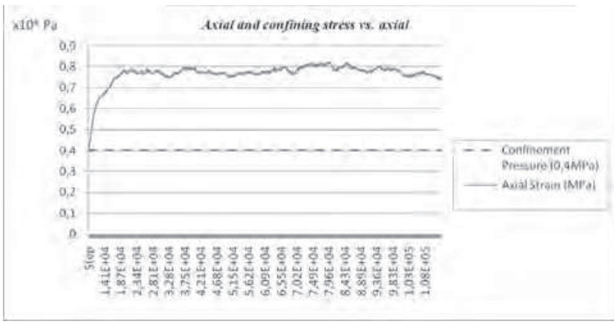

Figure 6. Axial and confining stress versus axial strain (Biaxial Test) (CP=0,4MPa)

Results and discussions

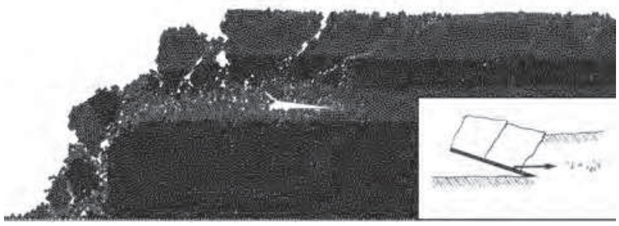

Figure 7. Side view of the loosening and clod generation by DEM and the theoretic aspect (SITKEI 1967)

The influence of the speed and the rake angle

The parallel-bond contact was used to describe the behavior of the cohesive soil (discontinuous) during soil-tool interface process. A series of models were analysed with various soil properties, speed and inclined angles using PFC2D Code. The results showed the significant effect of the tool incline angles and working speed on cutting forces in 20 cm depth.

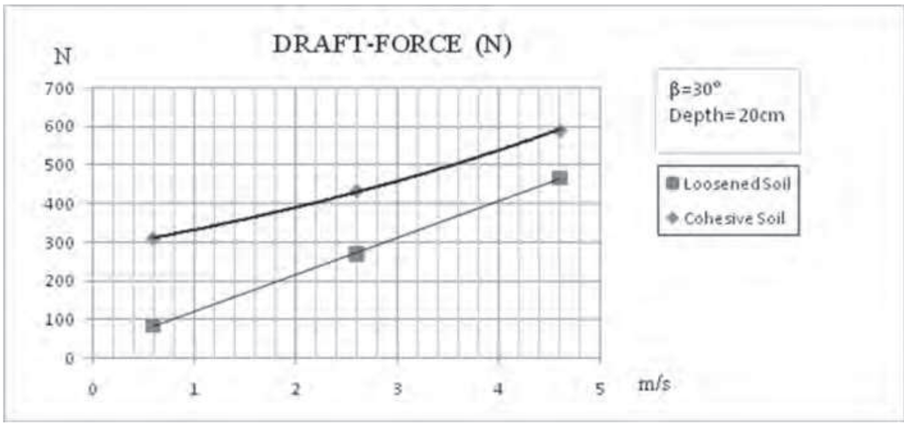

Figure 8. The influence of the speed (0,6-4,6 m/s) by DEM

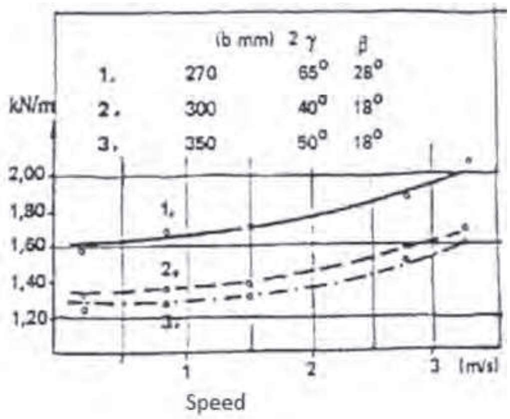

Figure 9. The Draft Force vs. velocity and ß angle (SITKEI 1967)

In this research between the two extremities (0,6-4,6 m/s and, 5°-30°) the results are parabolic. The parallel bonds produce cohesive forces between discrete particles, so parts of discrete particles are conglomerated and form particle aggregate clusters after the tillage process. The complete model is formed by bonding of elements in wide sizes. This structure of the model is similar to that of the actual cohesive soils.

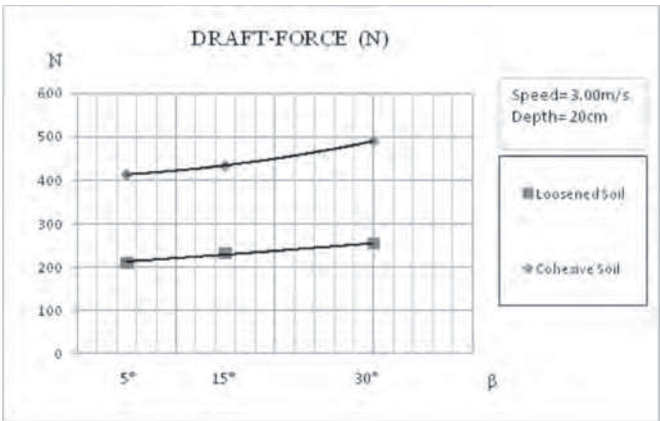

Figure 10. The influence of the incline resistant angle (5°-30°) by DEM

During the simulated tillage process by a cultivator sweep, soil evolves from the extrusion between soil clumps, the humping ahead of the tillage tool, and the climb along the surface of the sweep, to the rupture and separation of cohesive soil cluster.

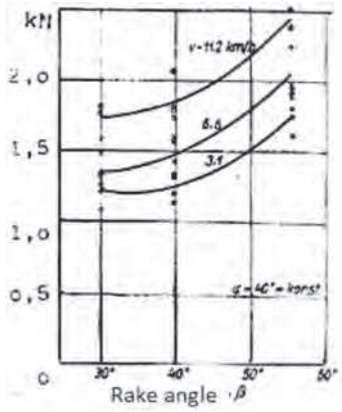

Figure 11. Draft Force - incline angle (ß) dependence (SITKEI 1976)

Conclusions

In this two dimensional discrete element analyses carried out to simulate soil-tool interaction and the comparison with the experimental results. The effects and draft-force of the tool geometry are very similar to the field tests. In the DEM numerical approach the parallel-bond contact was used to describe the behavior of the discontinuous, cohesive soil during soil-tool interface process. After the biaxial test method with which we validated the micro properties, a series of models were analyzed with various soil properties, speed and inclined angles using in the three dimensional models. The results showed the significant effect of the tool incline angles and working speed on cutting forces in 20 cm depth. Results calculated from the DEM model support the following conclusions:

– In case the set of the appreciable parameters in DEM synthetic material with parallel- bonds between the particles, we can synchronizing the virtual biaxial test (microproperties) and could be compared directly with the measured response of the physical material. The real soil macroproperties are the cohesion and the friction angle, that we got from the science articles (Kerényi 1996). With the parallel bonds we can model the presence of liquid bridges, which cause the cohesion in the artificial soil.
– Under the cutting process in 20 cm depth when the speed is increasing the draft force is increasing parabolic (Figure 8-9.).
– If the β angle is increasing the draft force is increasing parabolic as well (Figure 10-11.).

It can be concluded that the discrete element method can be used for simulating the soil cutting processes in non-homogeneous soils and for the investigation of soil loosening and sweep performance. The model can be used in development procedures of soil loosening tools, reducing the number of soil bin and field test.

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