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Modeling of Soil and Oscillatory Tine Interaction using Discrete Element Method

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Abstract: Interaction between soil and machine is essential challenge for researchers, developers, designers and manufacturers of agricultural machineries. Modeling of tillage equipment is an important Engineering work, however, interaction modeling is a complex process due to three-dimensional changes in soil, nonlinear soil behavior phenomenon and soil flow quality in connection area between the soil and tool and the dynamic effects of equipments. Appropriate simulation of the soil-tool interaction is a key point for the optimization of tillage tools and can eliminate required field tests with high costs and also reduces developing time for the proposed model. The purpose of this study is to develop a three-dimensional model of a soil-oscillating subsoiler using discrete element method, evaluate simulation frequency and oscillation angle effect on the performance of oscillating subsoiler and determining different parameters affecting the simulation results. For modeling soil mass as a granular material, the computer program PFC3D was used. For non-oscillating blade only included transition speed and for oscillating blade in addition to transition speed, angular velocity was also defined. Working depth was 38 cm and blade speed of 0.89 meters per second was defined. To evaluate the effect of frequency on subsoiler performance, different frequencies of 1.94, 3.3, 4.9, 6 and 8.8 Hz at amplitude of ± 69 mm and oscillation angle of 27 degree were simulated, as well as to know the effect of oscillation angle on oscillating subsoiler oscillation angles of 27 and -22.5 degrees in frequency of 4.9 Hz and amplitude of ± 69 amplitude were tested by simulation. In all oscillating tests in comparison with non-oscillating, with increasing frequency draft requirement decreased and good correlation was found between simulated nad experimental results. Simulation results showed that for positive oscillation angle during backing off phase tine bottom face compacted underside soil, while for negative oscillation angle of -22° underside soil compaction happened during cutting phase as front face cutting soil. Bottom view of soil rupture showed oscillatory tillage mode loosened more area than non-oscillatory mode.

Key words: Discrete Element Method, oscillatory subsoiler, draft, numerical simulation

INTRODUCTION

Gradually increase in the computational power of computers, discrete element method has become a more effective method for creating granular environments such as soil and biomaterial. This method can serve as a good alternative to a common approach like continuous methods, such as finite element method in analyzing systems that have a discrete nature. With the advent of such methods, theory about granular materials becomes closer to reality. Because the theory can be based on measurement details of granular particles deformation and acting forces on them.

Modeling interaction between soil and equipment in case that the dynamic effects are considered is complex. Discrete element method is used for modeling granular materials and also studying the relationship between microscopic and macroscopic behavior of material (Cundall and Struck, 1979). Discrete element method is able to show the breaking or creation of elements and the process by which creation of cracks can be observed. DEM is suitable for soil simulating, interaction between soil and rigid bodies (solid) or flexible bodies. Nonlinear soil behavior and interactions between soil –

tool can be easily described by this method and can be used as a tool for optimization of tillage equipments. Over the past 10 years, many studies showed the potential of DEM method for simulation the interaction between soil and tillage tools.

Discrete element method is capable of simulation large displacements of particles involved in soil tillage and soil behavior under vibrating loads. These benefits oscillating subsoiler modeling capabilities with discrete elements. PFC3D program offers elements movement and interaction with other spherical discrete elements. The program consists of mechanical behavior of peripheral rigid spherical particles under load. Modeling done by the program can be among the discrete element program based on reviews conducted by the Cundall and hart 1992 on discrete element method.

Calculation cycle is in PFC3D is an algorithm with time step, in each step few arithmetic operation would be repeated, operations such as applying Newton's second law for each particle, force and deformation law for any contact and updating the wall positions. Contacts that may happen between two structural elements are automatically created and destroyed during the simulation.

Starts each step where the situations of structural elements is advent, first identified contacts are formed. Then force-deformation law is applied to each contact, according to the relative amount of displacement between the two components in contact and selected contact model, values of contact forces are updated. Then applies movement law on each element. Thus, based on force and resultant torque created in contacts and applied forces to each element, speed, acceleration and particle displacement are calculated. Calculations are conducted in parallel with each other.

MATERIALS and METHOD

After calibration of macroscopic and microscopic properties of soil particles, PFC3D was used for modeling soil bin and blade. Soil box has length of 2 m, 0.5 m width and height of 1m created by walls, then it was filled with 46707 spherical particles as high as 0.6 m (Figure 1). Particles specifications detail is in Table 1. Soil bin includes 6 walls with hardness coefficients 1×108 and friction coefficient of 1. Parallel model was used because it capable of showing the soil brittle behavior, deformation and soil rupture better than the other models like contact model. The important parameters of parallel model includes, normal and shear stiffness, normal and shear bond strength and the radius coefficient of linkage. Then the tine was modeled with the dimensions specified in Figure 2 and its working depth was 38 cm inside soil particles.

Table 1. Soil properties

Particle density, kg/m^3	2960
Particle stiffness, N/m	3.2×10^5
Particle friction coefficient	1.3
Assembly stiffness, N/m	5.69×10^6
Bond strenght normal and shear, kPa	130
Bond stiffness normal and shear, kPa	500
Bond radius factor,	0.5

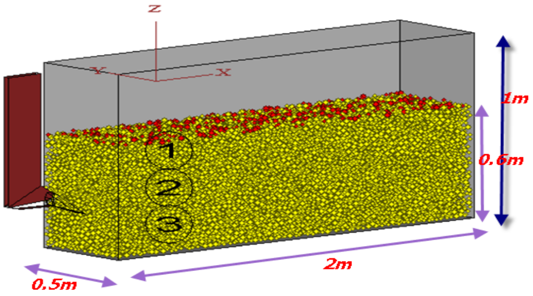

Figure 1. Soil box and soil particles inside that as tine moves to inside box

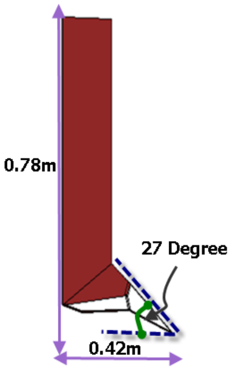

Figure 2. Subsoiler tines created using walls

Soil box was designed based on maximum number of particles and also to neutralize the impact edges of box. If soil box be smaller, forces or stresses transferred through the particles backward or forward to walls and certainly will have impact on the simulation results. To have sufficient space for the blade to balance forces during movement soil box was selected large enough. Tine dimensions were the same as tine used in the field and it was designed using flat walls through the programming.

To oscillate the tine the translation and angular velocities were determined while for no-oscillating tine determining translation velocity was enough. Angular velocity was defined as per Eq(1).

$$V = A\omega\cos(\omega t) \qquad (1)$$

Where:
V=Tine Velocity during oscillation, m/s
A= Amplitude, m
ω=Angular velocity, rad/s
t=time, s

Total tine velocity was defined as following Eq(2).

$$V_t = V_0 + V \qquad (2)$$

Where:
V_t=total tine velocity (translation velocity plus oscillation velocity), m/s
V_0=Translation velocity of tine, m/s

For all simulation runs translation velocity was 0.89 m/s, amplitude of ±69 mm, oscillation angle of 27° and oscillation velocity changed only by determining different frequencies of, 1.9, 3.3, 4.9, 6 and 8.8 Hz. For all simulation runs working depth was 38 cm.

RESULTS and DISCUSSION

Figure 3 shows tine tip path for positive oscillation angle of 27°, during cutting phase tine tip moves upward moving cut soil upward, causing increasing force because of soil acceleration. It is clear from figure 4 that during cutting phase only tine top face active and it cuts and accelerate soil, while during backing off phase tines goes back with certain angle. Its front face becomes passive and its underside active. Figure 5 shows that there is no action in front of tine and its bottom face compacts underside soil.

Simulation results showed when oscillation angle is negative the tine moves down and front during cutting phase(Figure 6). Figure 7 shows there is interaction between tine bottom and underside soil and compacts underside soil. However it compaction action effect was less than positive angle during backing off phase. During backing off phase tine front face move already cut soil upward and accelerate that (Figure 8).

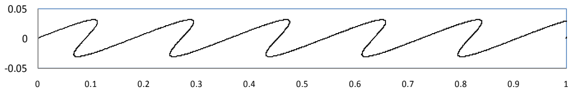

Figure 3. Tine tip path(x-axis is horizontal displacement and Y is vertical, at constant amplitude of ±69 mm and oscillation angle of 27°

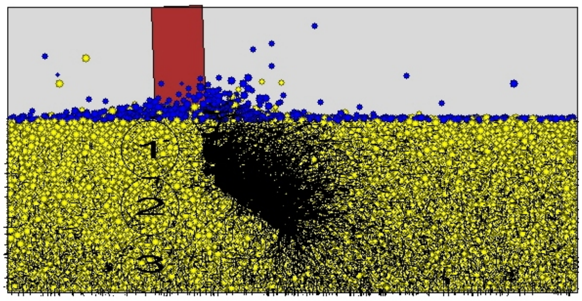

Figure 4. Tine cuting phase for oscillation angle of 27°

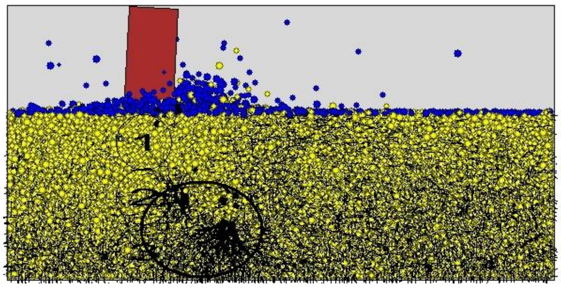

Figure 5. Backing off phase when tine top face was passive and its underside face compacts soil

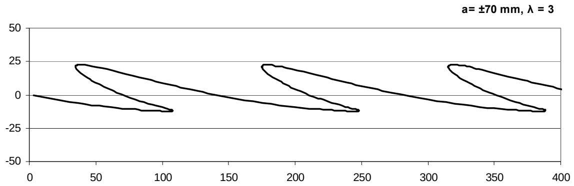

Figure 6. Tine tip path for oscillation ngle of -22°

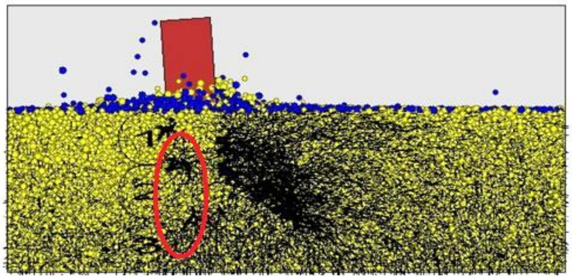

Figure 7. Negative oscillation tine (22°) during cutting phase

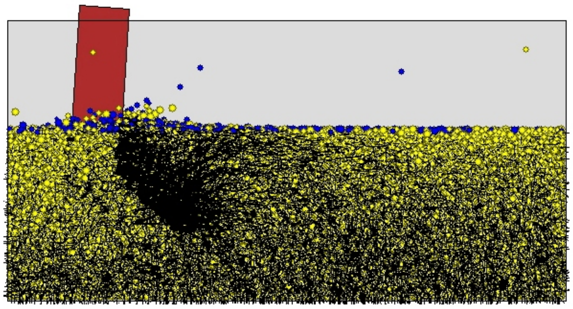

Figure 8. Negative osccillation tine (22°) during backing off phase

Figure 9 shows remained the tine bottom path, for oscillatory mode rupture area around tine was larger than rigid mode. Then for oscillatory mode in comparison to rigid mode more parallel links to more distance from the blades are broken, and this indicates that oscillator mode causes more soil looseness. Niyamapa and Salokhe (2000) studied soil failures by oscillatory tool. Experiments were conducted in soil bin on sandy loam soil at different frequencies, amplitudes and tool speeds. Rupture was observed in the crescent area, soil showed fragile treat with radial and transverse cracks. Mixing in the soil for oscillatory mode was more than non-oscillatory. Soil disturbance also increased with increasing frequency. Rupture area was divided two main layers called the deep zone and the surface zone. It was showed that in the deep layer soil was broken to the smaller pieces, while the region near the soil surface had larger pieces.

Both experimental and simulated results showed that with increasing frequency draft requirement decreased (Figure 10). This is because by increasing frequency cutting time decreased and backing off time increased. However draft requirement level was lower for simulated results. It was because of particle size and particles number. The real soil particle diameter is between 0.053 to 0.5 mm in diameter, while built particles for simulation were between 10 to 15 mm. Reduced particle diameter increases the number of particles adjacent to each other and increases the number of links involved to other particles and thus increases the daft.

Correlation coefficient of 0.93 between simulated and measured data showed that there was good agreement between them Figure 11.

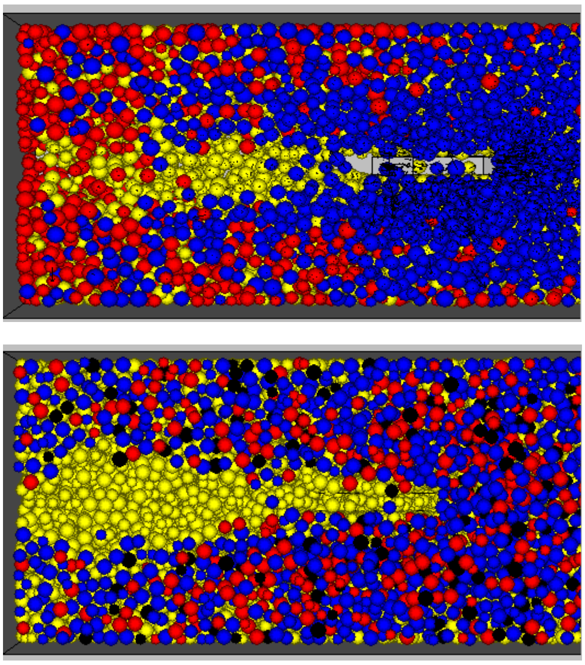

Figure 9. Soil rupture area around tine bottom for rigid tine (top) and oscillatory tine (bottom)

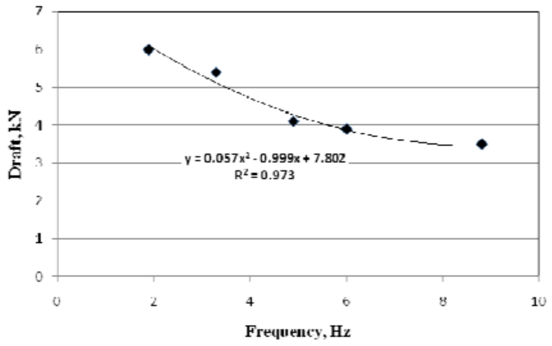

Figure 10. Draft requirement vs frequency increment

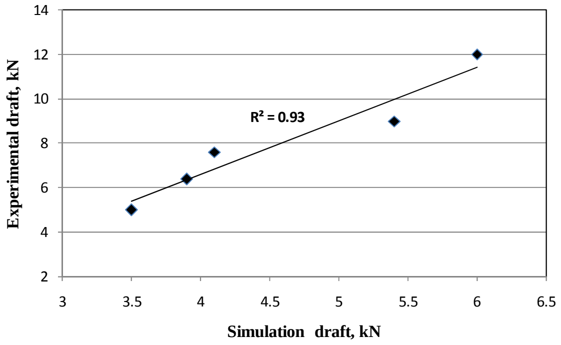

Figure 11. Correlation between simulated and experimental results

CONCLUSIONS

The followings were concluded from the study:

- Simulation showed that at positive oscillation angle of 27° tine front face was active during cutting phase while during backing off phase its bottom face was active and compacted underside soil. For large negative oscillation angle of -22° tine front and bottom face were actiove during cutting phase as front face cut soil its bottom compacted underside soil.
- Both experimental and simulated results showed that by increasing frequency draft requirement decearsed. Hower because larger prticle size used for simulation in comparison to smaller size of experimental soil particles, required draft from simulation result was lower than experimental results. For better and similar results their size should be decreased to closer size of soil.
- Bottom view of soil rupture showed that oscillatory tillage loosess more area than non-oscillatory mode.

REFERENCES

Cundall, P. A., D. H. Hart, 1992. Numerical modeling of discontinua. Journal Eng. Comput. 9: 101-113.

Cundall, P. A., o. D. L. Struck, 1979. A discrete numerical model for granular assemblies. Journal of Geotech. 29 (1): 47–65.

Niyamapa, T., V. M. Salokhe, 2000. Force and pressure distribution under vibratory tillage tool. Journal of Terramech. 37(3):139-150.