FEM model for the study of agricultural soil compaction under the action of two-wheel tractor

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Abstract: *This paper presents a theoretical model that allows estimating the state of tension in agricultural soil under the action of the wheels of a cultivator (two-wheel tractor), using the finite element method. Improper operation of cultivators and their improper use can lead to the degradation of agricultural soil by generating excessive mechanical stresses that favor the occurrence of artificial soil compaction. The finite element analysis models developed in this paper allow a dramatic reduction in the costs of experimental testing as well as the time required to estimate the possibility of artificial compaction of agricultural soil under the action of cultivators.*
KEYWORDS: *COMPACTION, FINITE ELEMENT METHOD (FEM), WHEELS, TWO-WHEEL TRACTOR*

1. Introduction

Artificial soil compaction is perceived as a mechanical pollution, which appeared as an effect of the mechanical loads induced by the passages made during the agricultural works by the two-wheel tractor.

There are factors that influence soil compaction, such as: soil properties (texture, bulk density, structure) [1], soil type, number of passes of agricultural machinery, contact pressure, soil moisture content, speed of agricultural machinery, the size and shape of the footprint between the tire and the ground, the wheel load [7, 5, 6]. Usually, the use of two-wheel tractor involves an increased number of passes on the ground, thus increasing the compaction of agricultural soil [1].

The cultivator is a specialized technical equipment used for preparing agricultural soil through a series of blades that are used to rotate the soil.

It can be adjusted according to the specific requirements of the soil. Tillage machines have become famous all over the world for preparing the germination bed in the field. These equipments are often used for breaking or processing the soil in greenhouses, solariums, landscaping, gardens, etc. [8].

The weight on the wheel (the size of the external load) directly and largely influences the distribution of stresses in the soil facilitating artificial compaction.
The tire pressure shown in Fig. 1 is of particular importance on the shape of the contact surface between the tire and the ground and implicitly on the distribution of stresses in the ground [9].
For different soil conditions (soil type, humidity, etc.), depending on the tire pressure, different stress distributions in the soil can be obtained [9].
The pressure distribution in the contact spot is not uniform, but varies along both the longitudinal and transverse axes. When the tire is running, the pressure distribution tends to be higher at the front of the contact spot [3].

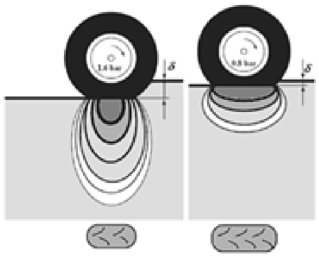

Fig. 1. *Influence of tire air pressure on the shape of the contact surface and on soil stress distribution*

Due to the fact that agricultural soil is not a homogeneous, isotropic and ideally elastic material, the mathematical modeling of the stress distribution phenomenon is quite difficult. The finite element method has proven to be extremely useful for modeling this phenomenon. For agricultural soils, stresses and strains are determined by measurements in laboratory conditions or directly in the field.

The finite element method is one of the numerical methods for obtaining approximate solutions of ordinary and differential equations that describe the phenomenon of stress distribution and deformation in the soil [3].

2. Materials and method

Using two-wheel tractor, primary and secondary processing operations could be combined in a single stage [9]. Therefore, agricultural soil could be prepared in a single pass with this type of tillage tools. This results in a decrease in the number of equipment passing through the field and subsequently results in a decrease in the artificial compaction of the soil that could be obtained due to excessive crossing of equipment in the field. Despite the high energy consumption, because the cultivator has the capacity to perform several types of tillage operations in a single stage, the total power required for this equipment is reduced [5]. Because the power of the cultivator is transmitted directly to the processing blades, the efficiency of power transmission in the two-wheel tractor is high [10].

In order to simulate with the finite element method the behavior of agricultural soil under the action of a two-wheel tractor's tire, shown in Fig. 2, we have a volume of soil with dimensions 1 m x 1m x 1 m

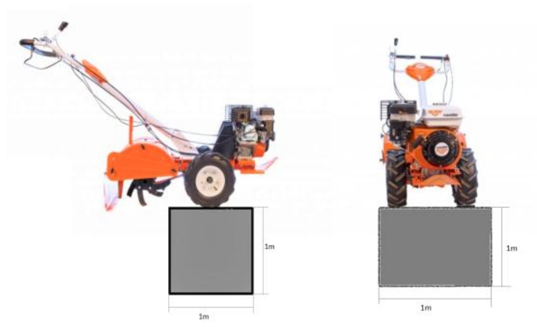

Fig.2 *Ruris 5800R two-wheel tractor*

Features of the Ruris 5800R two-wheel tractor [11]:

- Weight -70 kg
- working width - max 480 mm
- working depth max 150 mm

The simulation was performed for a soil type, having the following characteristics:

Cohesive soil (clay) with the characteristics [2]:
- Young's modulus of elasticity: $E = 3 \cdot 10^6$ Pa;
- Poisson's ratio: $\nu = 0{,}329$;
- cohesion: c = 18,12 kPa;
- angle of internal friction: $\varphi = 30°$;
- density: $\rho = 1270$ kg/m³;
- moisture content w = 24 %

3. Results and discussions

The simulation with the Finite Element Method was performed on a half model, in order to obtain the highest possible accuracy of the results.

Locks (fixings) were applied to the discretized model in two directions, so as to allow the ground to move only in the vertical direction.

For the simulation, the width of the contact spot was first fixed on the surface of the soil volume. It was considered that the force applied to the soil by the agricultural machine (contact pressure) is evenly distributed in the contact spot.

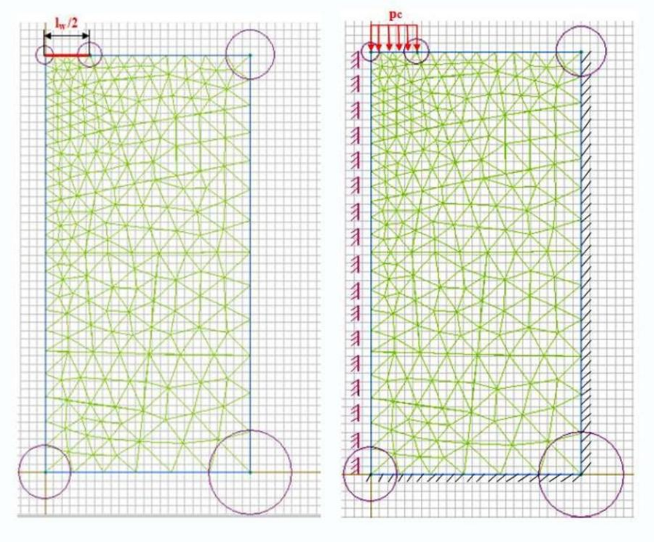

Fig. 3 *Meshed half-model of the analyzed volume of soil*

As a result of the application of the demands on the discretized model of the agricultural soil, different distributions of the equivalent stresses and of the displacements appeared in the soil were obtained, during the process of artificial compaction by the tire of the two-wheel tractor.

In Fig. 4 and Fig. 5 shows the distribution of equivalent stresses according to the von Mises criterion, respectively the distribution of displacements in the cohesive soil, in case the tire pressure of 0.1 MPa was considered. These models correspond to a contact pressure pc = 0.044 MPa, which is uniformly distributed in the contact spot whose area is A = 0.020m²

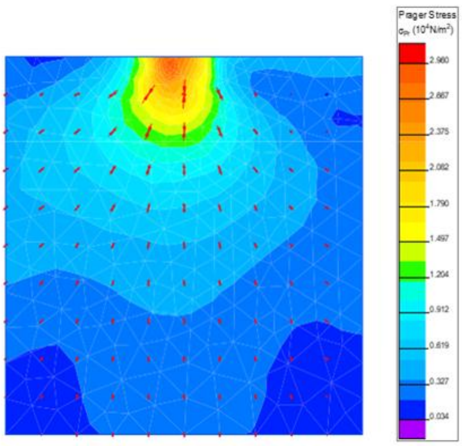

Fig.4 *Distribution of equivalent stresses in the cohesive soil (clay) in the longitudinal plane, for the contact pressure of 0.044 MPa and the width of the contact spot of 0.020m²*

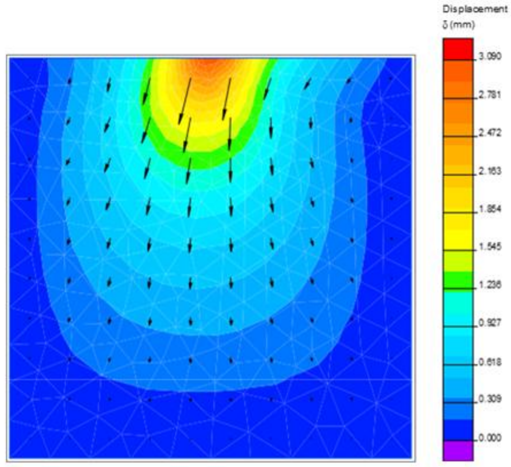

Fig.5 *Distribution of total displacements in the cohesive soil (clay) in longitudinal plane, for the contact pressure of 0.044 MPa and the width of the contact spot of 0.020 m²*

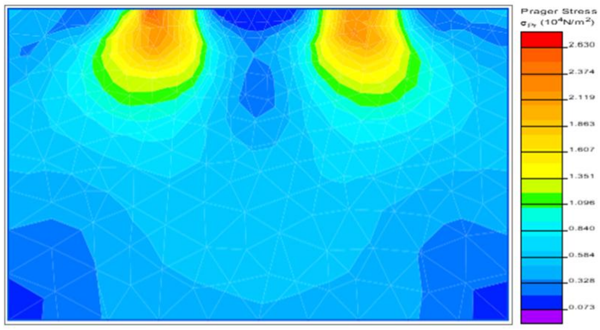

Fig. 6 *Distribution of equivalent stresses in cohesive soil (clay), for the contact pressure of 0.044 MPa and the width of the contact spot of 0.020 m²*

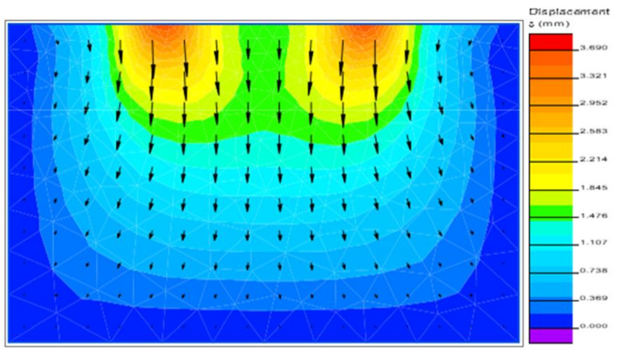

Fig. 7 *Distribution of total displacements in the cohesive soil (clay), for the contact pressure of 0.044 MPa and the width of the contact spot of 0.020m²*

The obtained results showed that, when applying a contact pressure pc = 0.044 MPa in the contact spot having the area of 0.020 m2 (width of the contact spot L = 0.12 m), in longitudinal plane, in the case of cohesive soil (fig. 4), maximum soil stresses of 2.88 MPa were obtained and they were concentrated in the upper part of the soil, at a depth of 10-12 cm, and the minimum stresses were of the order of 1.2 MPa, the maximum soil displacement clay being 10.8 mm.

In fig. 4 shows the distribution of equivalent voltages according to the von Mises criterion, respectively in Fig. 6 shows the distribution of displacements in the cohesive soil, obtained by simulation, in case the tire pressure of 0.1 MPa was considered. These correspond to a contact pressure pc = 0.044 MPa, evenly distributed in the contact spot having the area 0.020 m2 (width of the contact spot lw = 0.020m^2).

The obtained results showed that, when applying a contact pressure pc = 0.044 MPa in the contact spot having the area of 0.020 m2 (width of the contact spot L = 0.12 m), in frontal plane, in the case of cohesive soil (Fig. 6 and Fig. 7), maximum soil stresses of 2.64 MPa were obtained and concentrated in the upper part of the soil, at a depth of 10-12 cm, and the minimum stresses were of the order of 0.3 MPa, the maximum displacement of the clay soil being 10.8 mm.

4. Conclusions

Thanks to numerical calculation programs, it is possible to mathematically model the artificial compaction of the soil at the interaction with various working or rolling organs. The finite element method (FEM) is based on the discretization of a domain or a region into subdomains or subregions (finite elements), so on replacing a domain with an infinite degrees of freedom with a system with a finite number of degrees of freedom.

The reduction of the average pressure in the contact surface between the wheels and the ground is generally obtained by increasing the contact surface, a process that can be achieved mainly by the following methods: use of low tire pressures, equipping wheel cultivators with wide width, the use of special low-pressure or twin-wheel tires.

To reduce the pressure on the ground, it is recommended that the cultivator be equipped with large tires and that the tire pressure be adapted to the ground conditions.

The high pressure in the tire causes a small contact surface, the pressures distributed over a larger surface means that the stresses in the soil are concentrated in the upper layer, not in depth and the soil will decompact more easily.

At low pressures in the tire the tensions are transmitted deeper, and up to 1m in the ground sometimes, thus forming the compact layer (hardpan) at depths that do not reach the cultivator's knives.

5. Reference

1. Alakukku L., 1999 - Subsoil compaction due to wheel traffic. Agricultural and Food Science in Finland, vol. 8, pp. 333-351
2. Biriş S.Şt., 2010Mathematical modeling of agricultural soil compaction, Printech Publishing House, Bucharest;
3. Biriş S., Maican E., Ungureanu N., Vlăduţ V., Murad E. (2011). Analysis of stress and strain distribution in an agricultural vehicle wheel using finite element method, Proceedings of the 39 International Symposium On Agricultural Engineering "Actual Tasks on Agricultural Engineering", pag 107÷118, Opatija;
4. Culpin C. Farm Machinery. 10th edition. Granada: Granada Technical Books Press, Spain 1981.
5. Dexter A. R., Czyz E. A., Gate O. P., 2007 - A method for prediction of soil penetration resistance. Soil & Tillage Research, vol. 93, pp. 412-419;
6. Donaldson C. H., 1986 - Simple techniques for estimating soil compaction. Grootfontein College of Agriculture. Published Karoo Agric., vol. 3(7), pp. 55-58;
7. Gysi M., 2000 - Soil compaction due to heavy agricultural wheel traffic. Swiss Federal Institute of Technology, Zurich, Switzerland;
8. Hendrick JG, Gill WR. Rotary tiller design parameters, part III-Ratio of peripheral and forward velocities. Transactions of the ASAE 1971c; 14:679-683.
9. Topakci M, Celik HK, Yilmaz D, Stress analysis on transmission gears of a rotary tiller using finite element method. Akendiz Ünivresitesi Ziraat Fakultesi Dergisi, 2008; 21(2): 155-160.
10. Yatsuk, EP, Panov, IM, Efimov, DN, Marchenkoc, OS, Chernenkov AD. Rotary soil working machines (construction, calculation and design). 1st edition. Amerined publishing company. PVT. LTD., New Dehli. 1981.
11. https://www.ruris.ro/msc-content/uploads/products/cat-36/fise_tehnice/fisa-tehnica-motosapa-ruris-5800r-RURIS_5800R-ro.pdf