ADVANCED MODELLING OF STRESS DISTRIBUTION IN AGRICULTURAL SOIL UNDER DIFFERENT TRACTION DEVICES

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***Abstract**: In present, one of the most advanced methodology for modelling the phenomenon of stresses and strains propagation in the agricultural soil under different traction devices is the finite element method. Within the framework of this paper a mathematical model based on the finite element method and Drucker-Prager elastoplastic theory was used in the study of stress distribution in agricultural soil under the action of different traction devices of the tractors and agricultural machines, for various physical-mechanical properties of the soil.*
***Key words:** Traction device, Finite element method, Stress distribution, Soil compaction.*

INTRODUCTION

The passage of wheels over agricultural soils, which is usually of short duration in the case of most vehicles, results in soil artificial compaction. The compaction phenomenon of agricultural soil can be defined as an increase in its dry density and the closer packing of solid particles or reduction in porosity [E. McKyes, 1985], which can result from natural causes, including rainfall impact, soaking, and internal water tension. The most important factors, which have a significant influence in the process of artificial compaction of agricultural soil, are: the type of soil, moisture content of the soil, intensity of external load, area of contact surface between the soil and the tyre or track, shape of contact surface, and the number of passes.

Because the agricultural soil is not a homogeneous, isotropic, and ideal elastic material, the mathematical modelling of stress propagation phenomenon is very difficult.

Many mathematical models of stress propagation in the soil under different traction devices are based on the Boussinesq equations, which describes the stress distribution under a point load (Fig. 1) acting on a homogeneous, isotropic, semi-infinite, and ideal elastic medium.

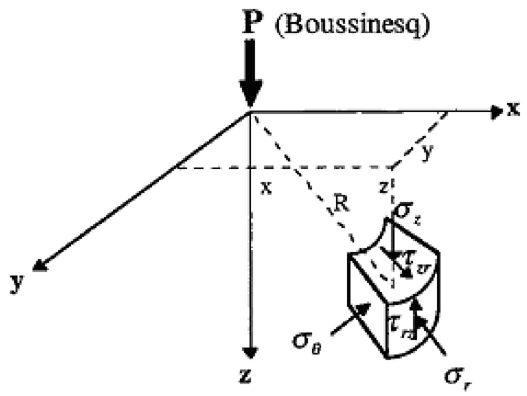


***Fig. 1.** Stress state produced by a concentrated vertical load [9]*

The stress levels are given in cylindrical coordinates as follows [9]:

$$\sigma_z = \frac{3 \cdot P \cdot z^3}{2 \cdot \pi \cdot R^5} \tag{1}$$

$$\sigma_r = \frac{P \cdot z^3}{2 \cdot \pi} \cdot \left[\frac{3 \cdot z \cdot r^2}{R^5} - \frac{1 - 2 \cdot \upsilon}{R \cdot (R + z)} \right] \tag{2}$$

$$\sigma_\theta = \frac{P \cdot (1 - 2 \cdot \upsilon)}{2 \cdot \pi} \cdot \left[\frac{1}{R \cdot (R + z)} - \frac{z}{R^3} \right] \tag{3}$$

$$\tau_{rz} = \frac{3 \cdot P \cdot r \cdot z^2}{2 \cdot \pi \cdot R^5} \tag{4}$$

where *P* –is the point load, υ -Poisson's ratio, $\sigma_{z,r,\theta}$ –normal stress components, τ_{rz} –shear stress component.

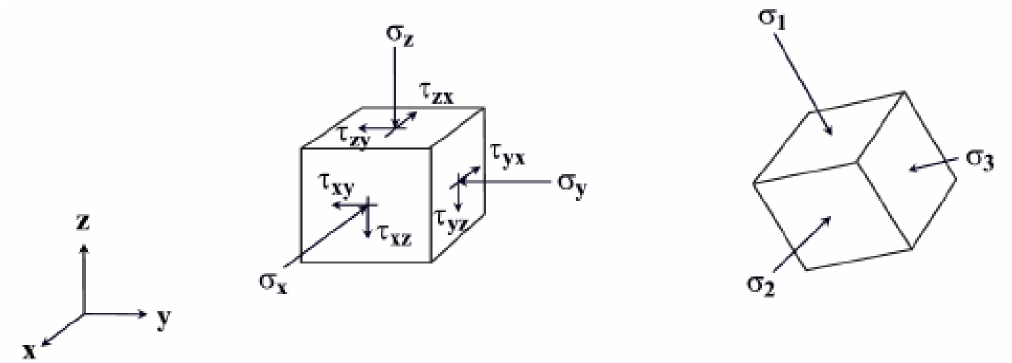


Fig. 2. *Stress tensor components [8]*

Figure 2 show the stress state in soil, of an infinitely cubic soil element. Stresses acting on a soil element can be described by mechanical invariants, which are independent of the choice of reference axes. The three invariants yield [7]:

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_x + \sigma_y + \sigma_z \tag{5}$$

$$I_2 = \sigma_x\sigma_y + \sigma_x\sigma_z + \sigma_y\sigma_z - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2 = \sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_2\sigma_3 \tag{6}$$

$$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{xz}\tau_{yz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_{xy}^2 = \sigma_1\sigma_2\sigma_3 \tag{7}$$

MATERIAL AND METHODS

The Drucker-Prager plasticity model can be used to simulate the behavior of agricultural soil. The yield criterion can be defined as:

$$F = 3 \cdot \alpha \cdot \sigma_m + \overline{\sigma} - k = 0 \tag{8}$$

where α and *k* are material constants which are assumed unchanged during the analysis, σ_m is the mean stress and $\overline{\sigma}$ is the effective stress, α and *k* are functions of two material parameters ϕ and *c* obtained from experiments, where ϕ is the angle of internal friction and *c* is the material cohesion strength.

In using this material model, the following considerations should be noted: strains are assumed to be small; problems with large displacements can be handled provided that the small strains assumption is still valid; the use of NR (Newton-Raphson) iterative method is recommended; material parameters ϕ and *c* must be bounded in the following ranges: $90 \geq \phi \geq 0$ and $c \geq 0$.

The required input parameters for the constitutive model of the agricultural soil are:

- Cohesion of soil (c): 18.12 kPa
- Internal friction angle of soil (φ): 30°
- Soil density (γ_w): 1270 kg/m^3
- Poisson's ratio υ_s: 0.329
- Young's modulus *E*: 3000 kPa

In this model, it was considered a soil volume with the depth of 1-2 meter, the width of 3-4 meter and length of 4-8 meter (Fig. 3) under the act of two different 45 HP tractors with tires and with caterpillar (U-445 and SM-445). The structural nonlinear analysis was made on the ideal model, which was considered the soil as if it were homogeneous and isotropic material. It was used the COSMOS/M 2.95 Programme for FEM modelling.

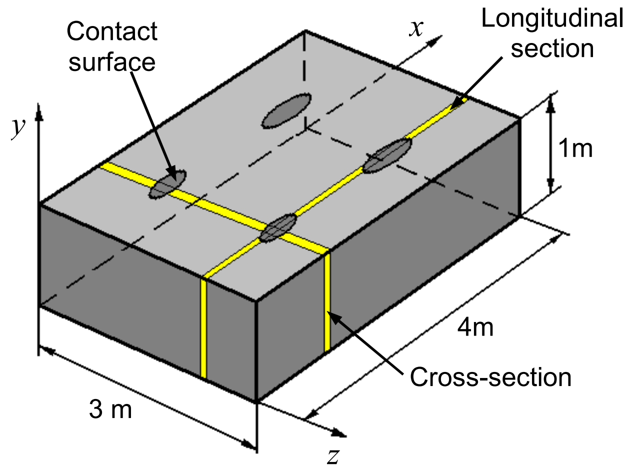


Fig. 3. *Analyzed soil volume*

Figure 4 show the distribution of vertical load in the contact area beneath agricultural tyres for three considerations: the real distribution with measured values (left), a model with uniform load distribution (centre), and a better model with un-uniform load distribution (right).

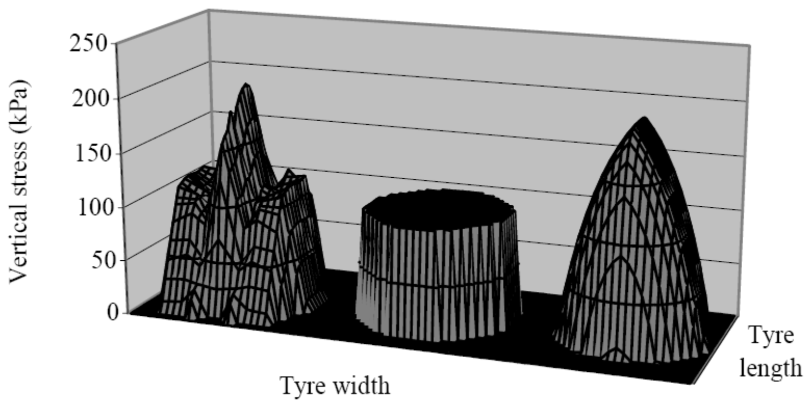
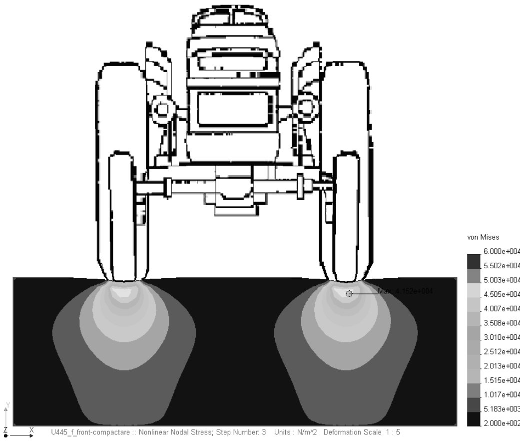


Fig. 4. *Distribution of vertical load in the contact area [7]*

RESULTS AND DISCUSSION

Figures 5 and 6 show the results of FEM analysis in cross-section and in longitudinal section for two Romanian 45 HP tractors with tires and with caterpillar (U-445 and SM-445). These results are: the stresses distribution in soil, and the graphical variation of stresses along the vertical-axial direction and along to the longitudinal direction.



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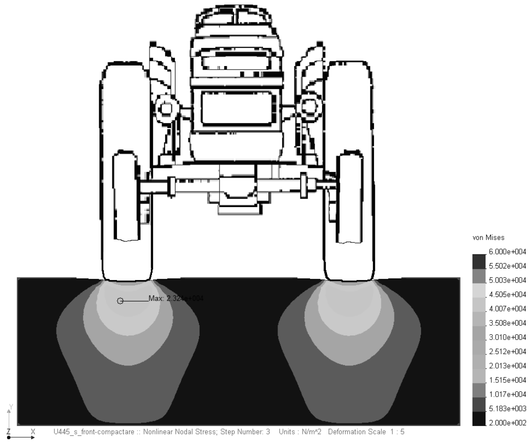

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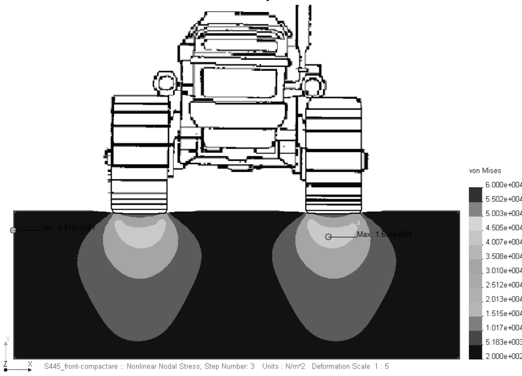

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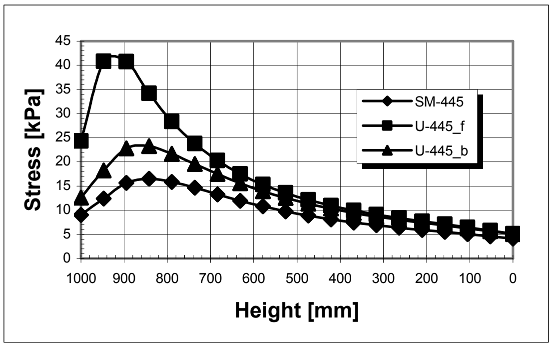
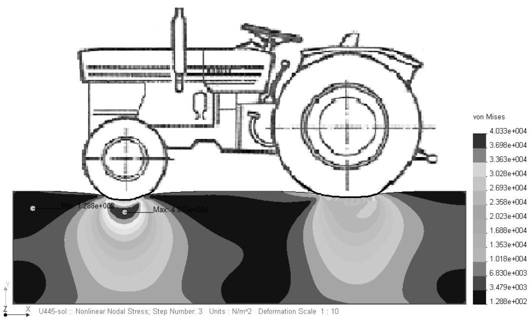
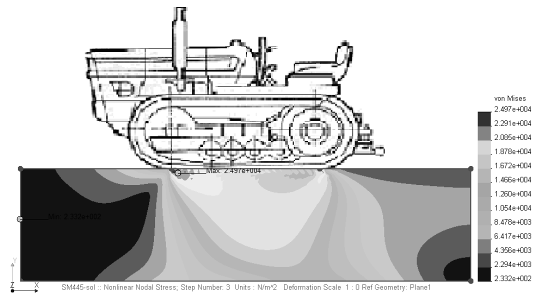
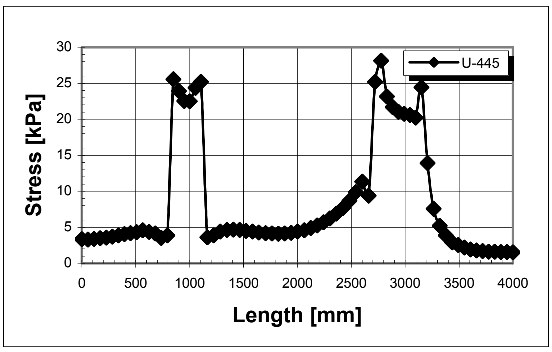


d)

Fig. 5. *Stresses distribution in cross-section for: a) front wheels of U-445 tractor, b) back wheels of U-445 tractor, c) SM-445 caterpillar tractor, d) graphical distribution along the axial-vertical direction*







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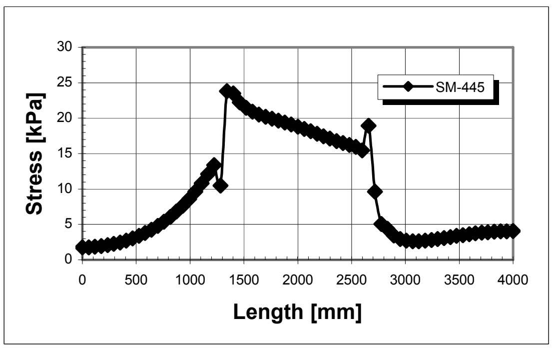

b)

Fig. 6. *Stresses distribution and graphical variation along the longitudinal direction to the top layer of the soil in longitudinal section for: a) U-445 tractor, b) SM-445 caterpillar tractor*

CONCLUSIONS AND FUTURE WORK

The Finite Element Method is in present the most advanced mathematical tool which can be used for the study of agricultural soil artificial compaction process. For mathematical modeling the soil is considered as a homogeneous and nonlinear material. From this study results that from these analysed tractors, the highest artificial compaction of soil there is in the case of the front wheels of U-445 tractor (see figure 5.d), when the equivalent maximum stress in soil is approx. 42 kPa. In these case is recommended to extend the contact area between the wheel and the soil. This study represents a seriously argument for implementation and using the caterpillar as a tractor device for the reduction of artificial soil compaction. The present researches are directed to using the rubber caterpillar, and also to using the reduce-pressure tyres with largest contact area with the soil.

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