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The variation of the unitary stresses occurring in the working part in relation to the type of soil, using the finite element method

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Abstract. Agriculture brings a major contribution to the sustainable development of the economy, providing food to people. Because of the continuous growth of the population, there is an ever increasing need of food worldwide. For this reason, it is necessary to study the contact between the soil and the active tool of the cultivators, in relation to the type of soil and its parameters. The physical-mechanical characteristics of the soils are influenced by the moving velocity of the working part, as well as by the humidity of the soil. The humidity triggers the change of the friction coefficient at the soil-steel contact, being of significant importance for the decrease of the working resistance of the working tools and responsible for increasing exploitation costs. The model used for the soil has a non-linear plastic behavior of the Drucker Prager type, being different from the Mises model. The programming software Ansys was used for the simulation with the finite element method, allowing the study of the behavior of the active working part, the normal stress being analyzed in real conditions, at various depths and velocities for a soil with a clay-sandy texture.

1. Introduction

For humankind on the whole, agriculture has a major contribution to the sustainable development of the economy, by providing food to people, thus ensuring their life on the planet.

The increase in productivity and economic efficiency in agriculture has been made possible by the continuous development of the mechanized agriculture technologies, specifically the use of ever bigger and heavier tractors and machines, leading to the intensification and expansion of some physical degradation processes, as well as to the anthropogenic destructuring and compaction of the soil. The Earth population has tripled in the last century, making it necessary for the world economy to grow over 20 times, the industrial production increasing over 50 times, leading to a 30 times higher fuel consumption[1].

According to the latest reports an area of 1ha of productive land is lost every six seconds due to various forms of degradation, so the future expansion of agriculture on a "horizontal" plane is no longer possible [1].

The soil is a complex environment that can be considered, for simplification purposes, as a combination of solid particles, organic matter and porous spaces that allow air breakthrough and water accumulation and movement. The share of soil particles in its volume, for an ideal productive soil, should be: 45% mineral particles, 5% organic matter, 25% porous spaces filled with water and 25% porous spaces filled with air [2].

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Research has shown that about half of the energy is used for cultivating the soil. This high energy consumption is caused by the large amount of soil to be engaged during cultivation because of the inefficient method of transferring energy from the working part to the soil [3].
During the processing process, especially while ploughing, the soil is subjected to great stress because of the agricultural machines.
The specific resistance is established by reporting the traction resistance force of the work part to the transversal section of the furrow that resulted after processing.
Experimentally it was noticed that aerated soils are characterized by lower apparent density and the specific resistance force to ploughing is lower compared to compressed soil. At the same time, once the soil humidity is lower the soil ploughing resistance is higher.
Knowing the value of the specific resistance force to ploughing and the specific resistance to soil work in general is highly important because they influence fuel consumption.
Studies have shown that the higher the apparent density of the soil and its resistance to penetration is the higher the consumption is too. Consequently, fuel consumption increases with the work depth of the active part.
The main research studies have focused on the interaction between the soil and the type of work, different soils (physical and mechanical traits of the soil), the working part (shape, angle) and working conditions (working depth, cutting width, velocity). Because of the complexity of the soil-machine system, analytical models are used, limiting the study to the geometry of the active plowshare, making a prediction of the forces resulting from engaging the soil.
The continuous development of computers combined with the improvement of the mathematical techniques and methods have led to the occurrence of new generations of very efficient software which have succeeded in simulating various agricultural operations. The determination model of the soil-tool system to be submitted to the finite element analysis consists in passing from a continuous structure having an infinite number of points to a discrete model with finite number of points called knots, covering the model in a discretization network [4, 5].

2. Material and Method

This study analyses the behaviour of the working tool, part of the soil processing machine, using the Finite Element Method (FEM) in three different stages. In the pre-processing stage, the objective was to design a three dimensional model in CATIA V5, in keeping with the geometry of the active element, represented by the Cartesian coordinates, together with a portion of the soil rendered as a parallelepiped shape. The second stage followed the introduction of conditions both for the working part, through the fastening of the plowshare frame, the moving direction and velocity, and for the soil, through the action of the cohesion and internal friction forces. In the third stage, called the processing stage, there is the simulation of the process of soil displacement done in real conditions, for various degrees of refinement of the discretization network in finite elements.
The experiments were made in the Western Plain of Romania on a soil of the non-carbonated chernozem (black earth) type with mainly clay-sandy texture.
The physical – mechanical properties of the material of the plowshare OLC 45 under the Romanian standard STAS 880-80 and the European standard SR EN 10083-2:1995 symbolized as 1C45 in table 1, are introduced in the pre-processing stage.

Table 1. Mechanical and physical characteristics of the 1C45 steel.

Steel brand	Tensile yield strength $Rp_{0,2}$ [MPa]	Ultimate tensile strength R_m [MPa]	Poisson Coefficient n_{med}	A [%]
1C45	410	800	0.3	14

To study the behaviour of the universal plowshare, we chose size 8 with the following constructive dimensions presented in table 2, where B is the plowshare width and g its thickness.

Table 2. Main dimensions of the universal plowshare.

B [mm]	220
g [mm]	6

The three-dimensional drawing of the plowshare created using the CATIA program is made respecting the real dimensions according to STAS 7247/1973 presented in figure 1.
Since the simulation of the soil displacement process done by the universal plowshare fitted on a tiller seeder combo (UPTSC) is tridimensional, a system of coordinates made of three axes (Ox, Oy and Oz) is introduced, the direction of the motion being represented by the Ox axis.
The motion of the plowshare takes place on the Ox alignment, the motion sense being opposite to the axes system, as showed (figure 2). The Oz orientation refers to the angle of the working part in relation to the field surface.

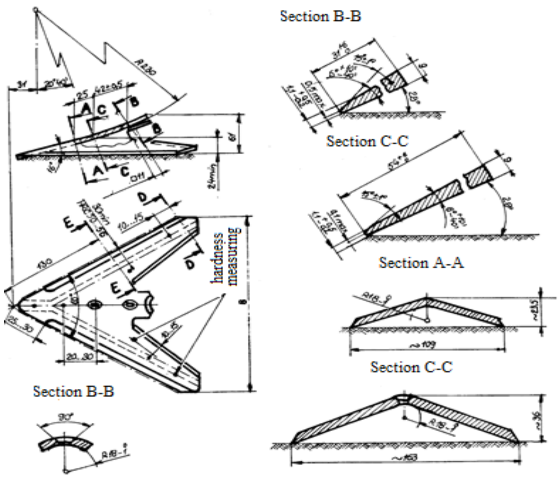

Figure 1. Universal plowshare schetck.

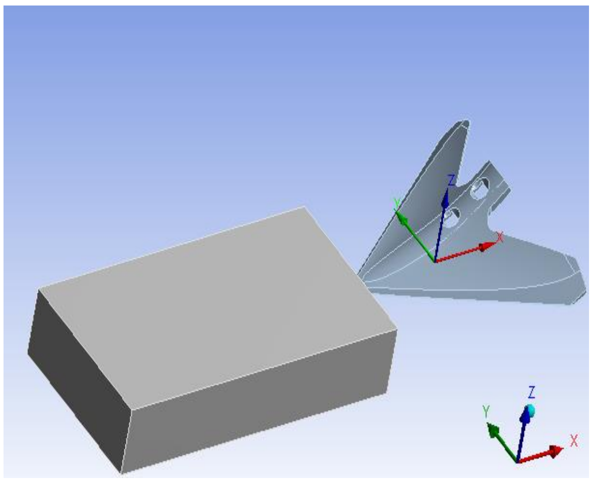

Figure 2. The axes system and the direction of the plowshare motion.

Considering the nonlinear plastic behavior of the Drucker Prager type of the clay-sandy soil, its characteristics are shown in table 3.

Table 3. Soil properties.

Soil Properties	Corresponding Values
Soil Type	Clay sandy
Young's modulus of elasticity (Es)	19000 kPa
Posson's ratio (η)	0.3
Cohesion (C)	23kPa
Internal friction angle (Ø)	32

We will conduct a three-dimensional study on the unitary stress according to the direction of the universal plowshare during the aeration process on the OX direction, for three different speeds (0.50, 1.00, 1.50 m/s), at different depths. The stress resistance force was established experimentally using pin transducers. It was used a VISHAY - HS 100 MG7128 type force cell of 1000 kN, invertor number FO21633 – USA, calibrated on 20.09.2015. For the measurements it was used a data system

consisting of a laptop and the master unit – Traveller 1, model MUT – 1, 1016-S type with 8 SG-2 type tensometric amplifying channels with a transmission band of 1kHz.
The results were obtained on a sandy clay soil at different depths, synthetized in table 4.
After introducing the mechanical characteristics of the plowshare material as well as the soil properties, we need, for the simulations set, to choose the optimum discretization for the working part (plowshare) as well as the constraints within the system, according to the importance during the working process. Thus, for the plowshare, we choose a discretization of 1 mm and for the soil 3 mm, to shorten the time needed for cycles rolling.

Table 4. Maximum and minimum normal stress at different velocities and depths.

No.	Velocity v [m/s]	Depth a [m]	Traction resistance R_{tr} [N]	Maximum normal stress [MPa]	Minimum normal stress [MPa]
1	0.50	0.18	4892	221.83	-184.49
2		0.25	6946	228.42	-189.45
3		0.36	8694	236.28	-462.63
4		0.38	9000	240.48	-584.47
5	1.00	0.18	6498	261.61	-205.5
6		0.25	8394	273.39	-215.2
7		0.36	9743	293.26	-224.71
8		0.38	9962	297.51	-226.4
9	1.50	0.18	7115	503.48	-257.79
10		0.25	7678	649.52	-253.84
11		0.36	12510	715.61	-248.27
12		0.38	12600	795.69	-147.36

In relation to the maximum stress σ_{max} and the minimum one σ_{min} determined by using the plowshare model with the finite elements (table 4), we calculated the wear and tear determining the wear safety coefficients for different depths. We determine the average value of the stresses σ_m and the stress range σ_a as follows:

$$\sigma_m = \frac{\sigma_{max}+\sigma_{min}}{2}; \ \sigma_a = \frac{\sigma_{max}-\sigma_{min}}{2} \quad (1)$$

The asymmetry coefficient of the cycle is given by the ratio between σ_{min} and σ_{max}:

$$R = \frac{\sigma_{min}}{\sigma_{max}} \quad (2)$$

The wear and tear determination starts from the wear limit for the alternating symmetric cycle which is calculated using the formula :

$$\sigma_{-1}=0.25(\sigma_R+\sigma_C)+50 \text{ [MPa]} \quad (3)$$

The maximum range of the cycle after Soderberg is determined according to the yield limit σ_c, while after Goodman it is in relation to the shear strength:

$$\sigma_{aS} = \sigma_{-1}\left(1-\frac{\sigma_m}{\sigma_c}\right); \quad \sigma_{aG} = \sigma_{-1}\left(1-\frac{\sigma_m}{\sigma_R}\right) \quad (4)$$

The safety coefficient for variable stresses after the Soderberg criterion and after the Goodman criterion is determined using the following formulae:

$$C = \frac{1}{\frac{\sigma_a}{\sigma_{-1}}+\frac{\sigma_m}{\sigma_c}}; \quad C = \frac{1}{\frac{\sigma_a}{\sigma_{-1}}+\frac{\sigma_m}{\sigma_R}} \quad (5)$$

Following the determinations, the following safety coefficients dependent on the texture type were reached (table 5):

Table 5. The safety coefficients after Soderberg and Goodman criteria.

Velocity v [m/s]	The safety coefficient after Soderberg		The safety coefficient after Goodman	
	Depth min a = 0.18 [m]	Depth max a = 0.38 [m]	Depth min a = 0.18 [m]	Depth max a = 0.38 [m]
0.5	0.93	1.00	0.91	0.94
1.0	0.94	0.95	0.91	0.91
1.5	0.99	1.02	0.93	0.95

One can notice following simulation that for a clay - sandy soil at a velocity v= 0.5 m/s, the maximum normal stress on OX direction is 221.83 MPa (figure 3), for a depth of a = 0.18 m, and 240.48 MPa for a = 0.38 m (figure 4). To move the plowshare with the velocity of 1.0 m/s, the maximum normal stress is 261.61 MPa (figure 5) at 0.18 m depth, while for 0.38 m depth, the maximum normal stress is 297.51 MPa (figure 6).

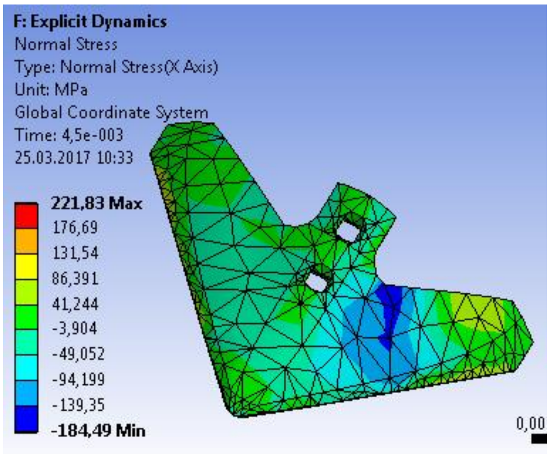

Figure 3. Normal stress on movement direction x, at v=0.5m/s, a=0.18m, for clay – sandy soil

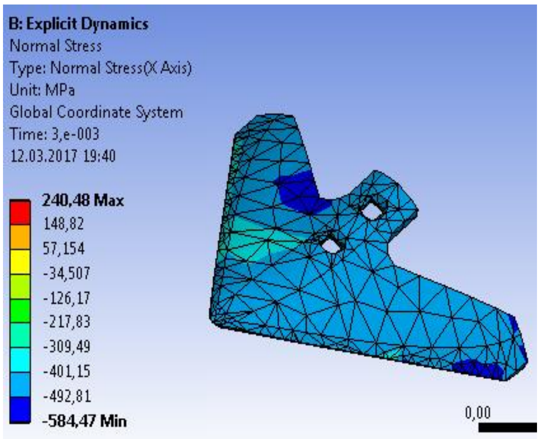

Figure 4. Normal stress on movement direction x, at v=0.5m/s, a=0.38m, for clay – sandy soil.

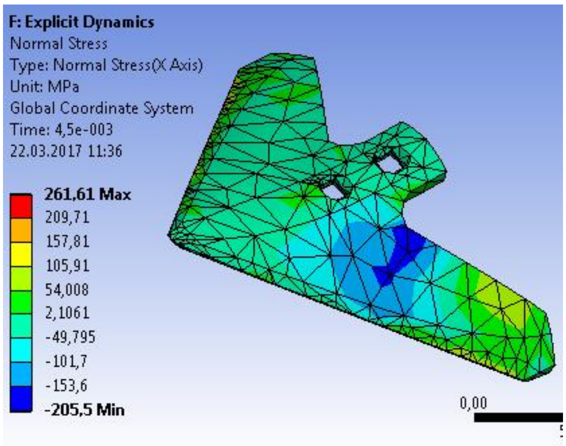

Figure 5. Normal stress on movement direction x, at v=1.0 m/s, a=0.18m, for clay – sandy soil.

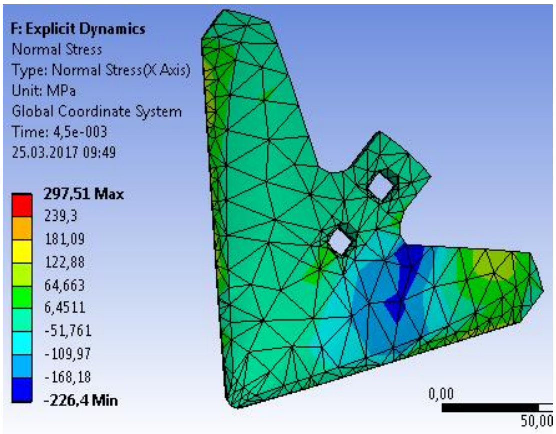

Figure 6. Normal stress on movement direction x, at v=1.0 m/s, a=0.38m, for clay – sandy soil.

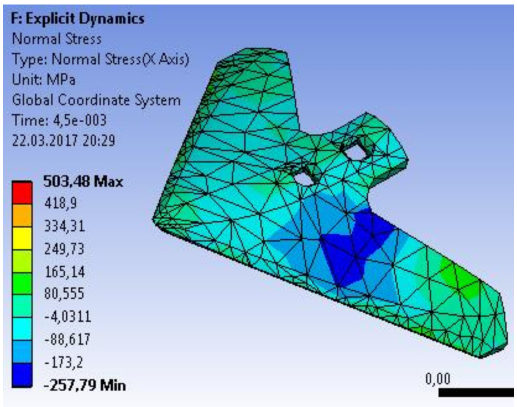

Figure 7. Normal stress on movement direction x, at v=1.5 m/s, a=0.18m, for clay – sandy soil.

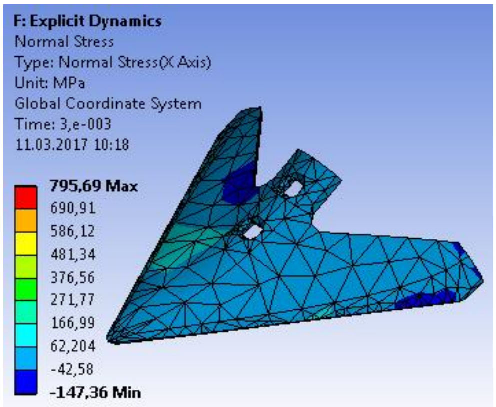

Figure 8. Normal stress on movement direction x, at v=1.5 m/s, a=0.38m, for clay – sandy soil.

3. Conclusions

A representative set of 12 problems was made on the soil dislocation process using the plowshare being differentiated by the different speed values and depth.

All the 12 problems on the soil aeration process were solved using numerical simulations and the Ansys software package, applying the same refinement degree of the same discretization network into finite elements in Cartesian coordinates.

From the wear stress calculations made by determining the safety coefficients resulted that although the plowshare resists to static stress it does not resist to the wear stress at the oscillating loading cycle it is subjected to in the soil.

According to the Goodman criterion it is subunitary for all the three speed values as well as for the work depths 0.18; 0.25; 0.36; 0.38 m which means that the plowshare is stress resistant.

According to the Soderberg criterion, the safety coefficient is subunitary for all the three speed values analyzed, at a depth of 0.18 m (for v=0.5 m/s, C=0.93, for v=1.0m/s, C=0.94; for v=1.5m/s, C=0.99) which means that the plowshare is stress resistant. At high depths the safety coefficient is higher than the unitary value (C=1.00; 1.05) which indicates that cracks may appear due to variable stresses. This can lead to irreversible deformations or the breaking of the working part. The cause of this phenomenon is due to the stress the work part is subjected to as it is higher than the yield limit or the shear limit of the material it is made of, fact confirmed also by the finite element simulations.

Consequently, special actions are required to increase the durability of the active parts used in working the soil in different methods as covering the surface with titanium based ceramic materials. Bases on the resulting conclusions it can be considered continuing the research process with other parts, at different speed values and depths to compare the results of the finite element simulation with those obtained experimentally.

4. References

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