

STRUCTURAL ANALYSIS WITH FINITE ELEMENTS OF A SUBSOILER WORKING PART

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ANALIZA STRUCTURALĂ CU ELEMENTE FINITE A ORGANULUI DE LUCRU AL UNUI SUBSOLIER

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ABSTRACT

The paper presents the way to perform a static analysis with finite elements for the working part of a subsoiler, together with its results. The analysis was made for two different working regimes: a regime in which the working depth of the subsoiler is 0.3 m, and the speed of advance of the aggregate during the work is 2.777 m/s and one in which the working depth is 0.4 m, and the speed of advance is 2.222 m/s. The results of this paper are addressed first of all to the designers of agricultural machines for soil tillage, but not only.

REZUMAT

În lucrare este prezentat modul de realizare a unei analize statice cu elemente finite pentru organul de lucru al unui subsolier, împreună cu rezultatele acesteia. Analiza a fost realizată pentru două regimuri de lucru diferite: un regim în care adâncimea de lucru a subsolierului este de 0,3 m iar viteza de înaintare a agregatului în timpul lucrului este de 2,777 m/s și unul în care adâncimea de lucru este de 0,4 m iar viteza de înaintare este de 2,222 m/s. Rezultatele din această lucrare se adresează în primul rând proiectanților de mașini agricole de lucrat solul, dar nu numai.

INTRODUCTION

Manufacture of working parts of soil tillage machines (and not only) in optimal conditions, assumes that the model made by the design engineers will go through some defined processes. These are: modeling, simulation and analysis processes with the help of CAD software (Computer Aided Design). All of this before sending them to the actual execution. Researchers at home and abroad have contributed to the database of these types of analyses by making it possible, lately, obtaining results as close to reality as possible (Cardei and Konstandinov, 2012, Gheorghe et al., 2016; Kadam and Chhapkane, 2017; Gheorghe et al., 2018; Biris et al, 2016; Gheorghita et al., 2018, Petru and Konstandinov, 2012, Nagy et al, 2011, Mollazade and Jafari, 2010, Xin et. al, 2013). The finite element method is a numerical method that can be used to accurately determine solutions to complex engineering problems. Currently, the finite element method is considered to be one of the best methods for efficiently solving a wide variety of practical problems, involving partial differential equations, (Biris, 2005). The essence of the finite element method is the discretization of a domain or a region in sub-domains or sub-regions (finite elements). In fig.1 are presented the stages of the analysis using the finite element method.

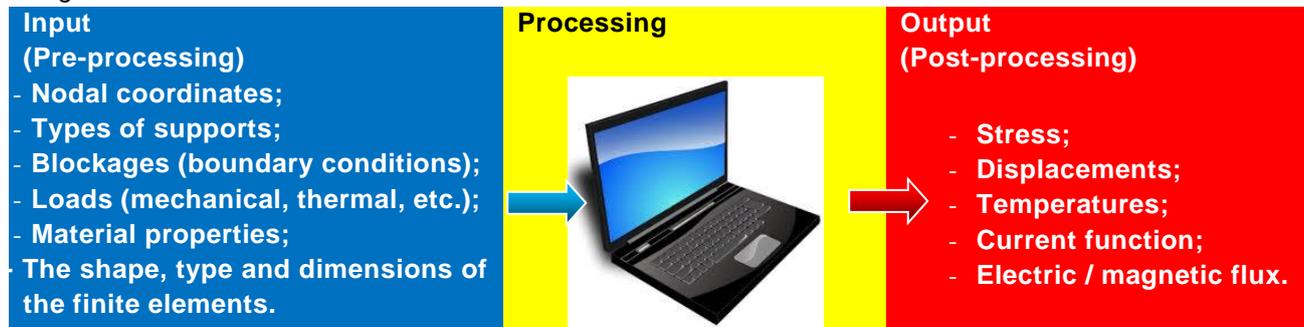


Fig. 1 - Analysis stages using the finite element method, adapted after Lates (2008)

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The purpose of this 3D numerical simulation study with finite elements was to simulate the behaviour of the working part structure of a subsoiler. The structure being subjected to stresses that arise during operation for two different working regimes.

MATERIALS AND METHODS

The role of the working part of a subsoiler is well known. It has to work at slightly greater depths to loosen the soil in depth and to break that layer of hardpan that prevents water from infiltrating the soil. Due to the working regime in the working parts, quite high stresses appear.

In the first stage of this study, the three-dimensional geometric model of the working part for a Maschio Gaspardo subsoiler, Artiglio 250/5 model, was realized. For this purpose, 3D modelling was performed with the Solid Works Premium 2016 S.P. 0.0 parameterized design program.

The three-dimensional modelling of the working part was performed in the "Parts" module of the design program, in fig. 2 different views of the obtained model are presented, as well as the Solid Works program interface.

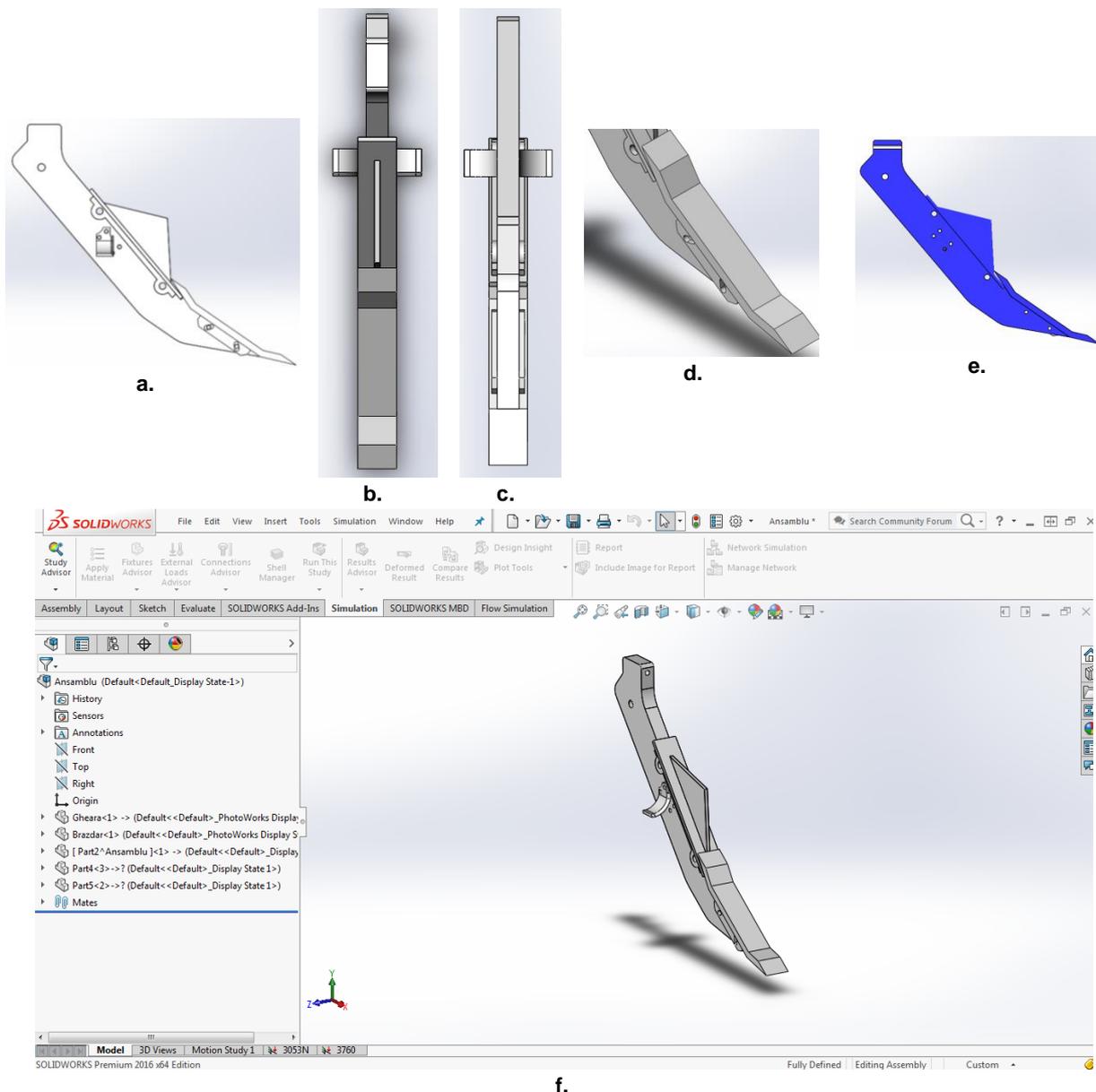


Fig. 2 - Views of the working part from the subsoiler Artiglio

a. Side view, b. top view, c. bottom view, d. detail on the coulter, e. longitudinal section, f. isometric view of the working part, as well as the interface of the software used

After completing this step, we proceeded to the next step which was to introduce the 3D geometric model of the working part in the "Simulation" module of the design program. According to *Gheorghe et al., (2019)*, the material most commonly used in the fabrication of the working part of the subsoilers is the 16MnCr5 alloy. In table 1 the characteristics of the material used in the manufacture of the working part are presented, and in fig. 3 the fatigue resistance curve of this material is presented.

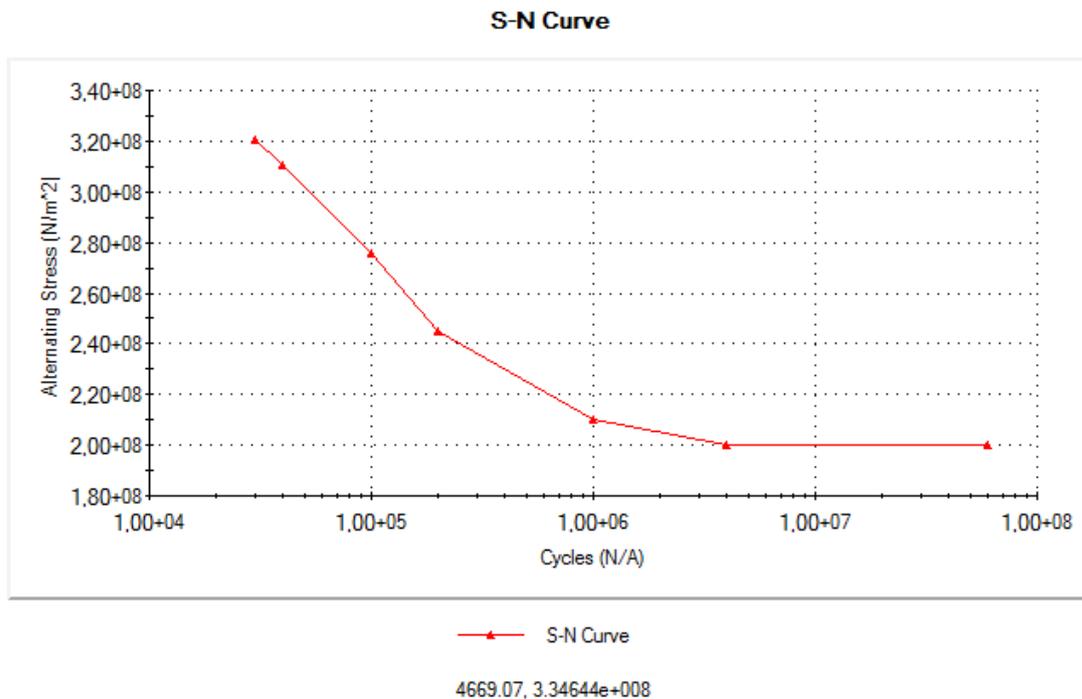


Fig. 3 - Fatigue curve of the 16MnCr5 alloy used to make the subsoiler working part, (Santosh et. al., 2013)

Table 1

Properties of 16MnCr5 alloy steel

Mechanical property	Value	Unit of measurement
Elastic Modulus	2.100000031e+011	N/m ²
Poisson's Ratio	0.28	-
Shear Modulus	7.9e+010	N/m ²
Mass Density	7800	kg/m ³
Tensile Strength	800000000	N/m ²
Yield Strength	590593984	N/m ²
Thermal Expansion Coefficient	1.1e-005	1/K
Thermal Conductivity	14	W/(m·K)
Specific Heat	440	J/(kg·K)

After choosing the material and introducing the characteristics of the material, the faces on which the forces act were selected and then the advancement resistance on the main working part of the subsoiler was calculated. The total force was calculated using the relations from *Letosnev (1959)*, *Krasnicenko (1964)*, *Sandru et. al (1983)*, *Scripnici and Babiciu (1979)*. It should be noted that two simulations were performed for two different working regimes. First regime is described by 0.3 m working depth of the subsoiler and 2.777 m/s aggregate speed of advance and the second one with 0.4 m working depth and 2.222 m/s advance speed. Thus, the resistance to advancement, in the general case, can be determined by the relation:

$$R = R_1 + R_2 + R_3 \tag{1}$$

in which: R_1 is the resistance to the subsoiler's own movement; R_2 is the opposite resistance to cutting and deforming the soil; R_3 is the opposite resistance to overturning and lateral displacement of the soil.

Resistance R_1 is given by the relation:

$$R_1 = f \cdot G_{org} \tag{2}$$

where f is the friction coefficient between the soil and the working part of the subsoiler (according to *Scripnici and Babiciu, 1979*, $f = 0.15 - 0.5$); for this study it was considered that $f = 0.3$, G is the gravity force of the

working part together with the weight of the frame which is the sole of the working part (in the study it was considered $G = 2825$ N).

Resistance R_2 opposite to cutting, loosening and deformation of the soil is given by the relation:

$$R_2 = k \cdot a \cdot b \cdot n_{org.} \quad (3)$$

where k is the resistance of the soil to cutting, loosening and deformation, a is the working depth, b is the working width of the part, and $n_{org.}$ is the number of parts.

According to *Scripnic and Babiciu (1979)*, depending on the type of soil, k has the following values: 250-350 Pa for light soils; 350-550 Pa for medium soils; 600-800 Pa for heavy soils and 800-1400 Pa for very heavy soils. The value of 1000 Pa was chosen for this study. As mentioned above, the working depth has two values 0.3 m and 0.4 m, for the same working width $b = 0.07$ m. Because the study is done on a single working part and not on the entire subsoiler, it will be considered $n_{org.} = 1$.

Resistance R_3 opposite to the displacement of the soil is calculated with the relation:

$$R_3 = \varepsilon \cdot a \cdot b \cdot v^2 \quad (4)$$

According to *Scripnic and Babiciu (1979)*, ε takes values between 150 and 200 daNs²/m⁴. For this study it was considered $\varepsilon = 180$ daNs²/m⁴, a and b have the same values as above as for v the two values were considered: one of 2.777 m/s for $a = 0.3$ m and one of 2.222 m/s for $a = 0.4$. Thus, the two resistances for advancement corresponding to the two working regimes are: $R_1 = 3053$ N and $R_2 = 3760$ N. The values of these forces were applied in the two static studies on the top of the ploughshare (see fig. 4).

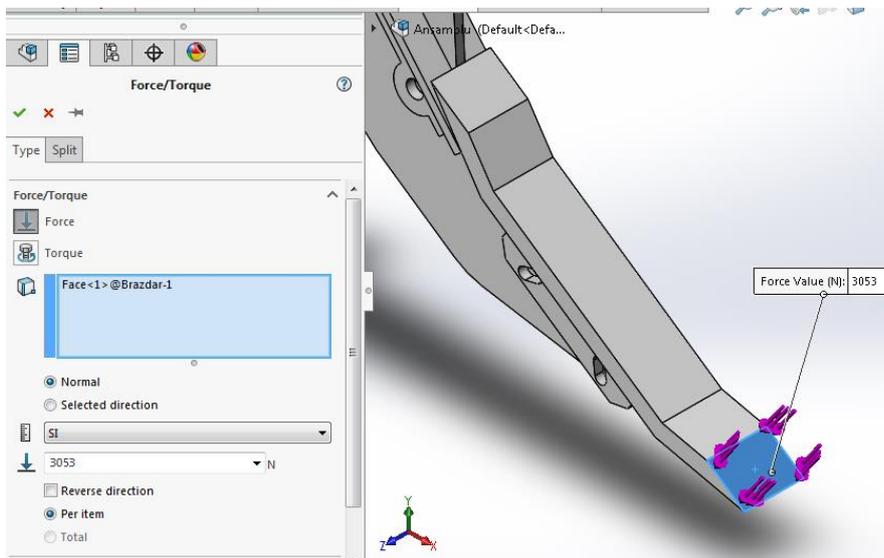


Fig. 4 - The place where the maximum resistance to advancement was applied

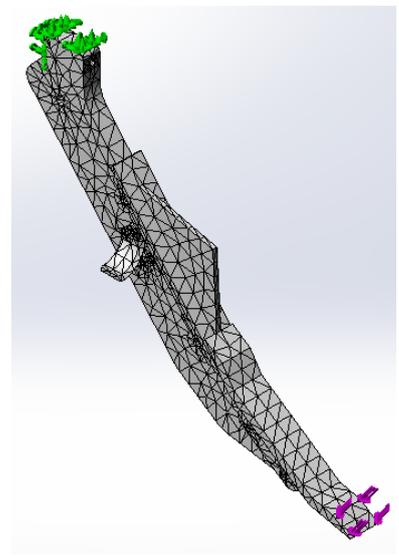


Fig. 5 - Finite element discretization of the geometric model

The finite element discretized model of the working part is presented in fig. 5. After the discretization of the finite element network the simulation was run, its results being presented below.

Following the simulation, the design program provided the results obtained in graphical form. The geometric pattern is divided into areas of a certain colour. Each area comprising the region of the geometric model in which the analysed size has the value specified in the chromatic legend on the right side of the screen.

RESULTS

For the working part model for the modelled and analysed subsoiler, the results obtained from the simulation in Solid Works are presented below. Thus, in figure 6 the values of the displacements that appear in the working body are presented during the defined stresses.

Analysing this data, it can be observed that the largest displacements of the nodes in the structure of the subsoiler working part appear on the peak of the ploughshare in both working regimes (as expected, otherwise). Its maximum value being 1.034 mm in the case of the first working regime and 1.302 mm in the case of the second working regime.

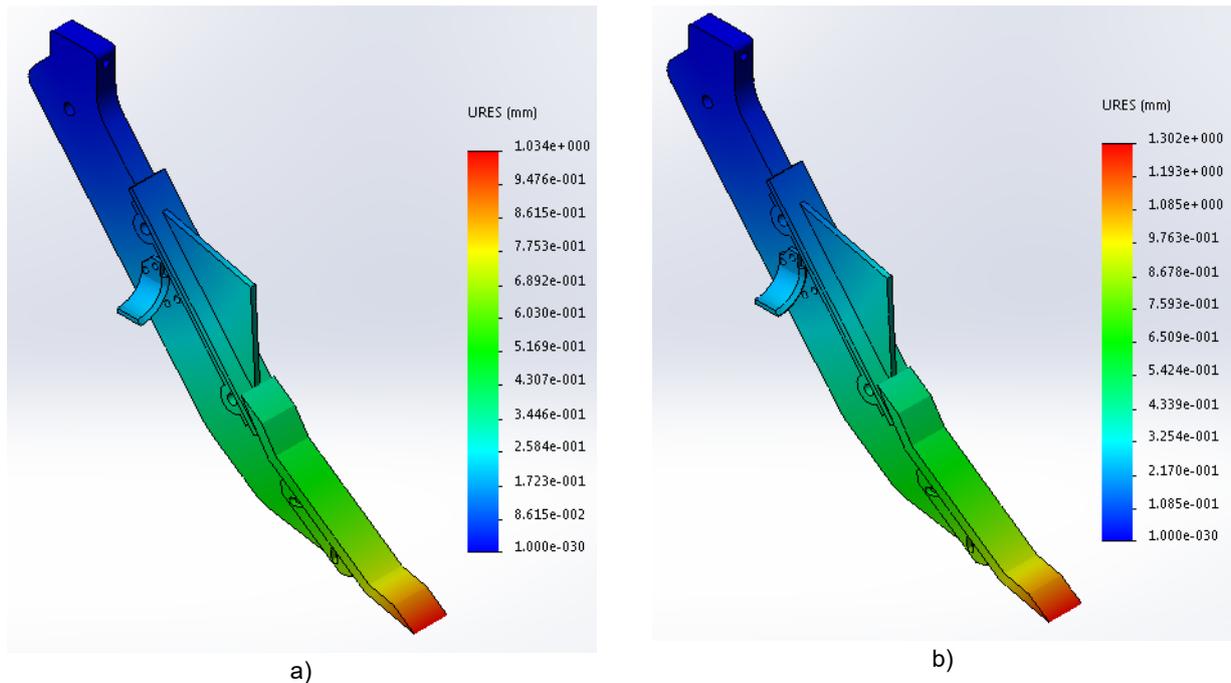


Fig. 6 - The values of the displacements that appeared in the working part during the two working regimes:
 a) $a = 0.3\text{ m}$ and $v = 2.777\text{ m/s}$; b) $a = 0.4\text{ m}$ and $v = 2.222\text{ m/s}$

In figure 7 the values of the equivalent tensions in the working part are presented for the two analysed cases, stresses calculated according to von Mises criterion.

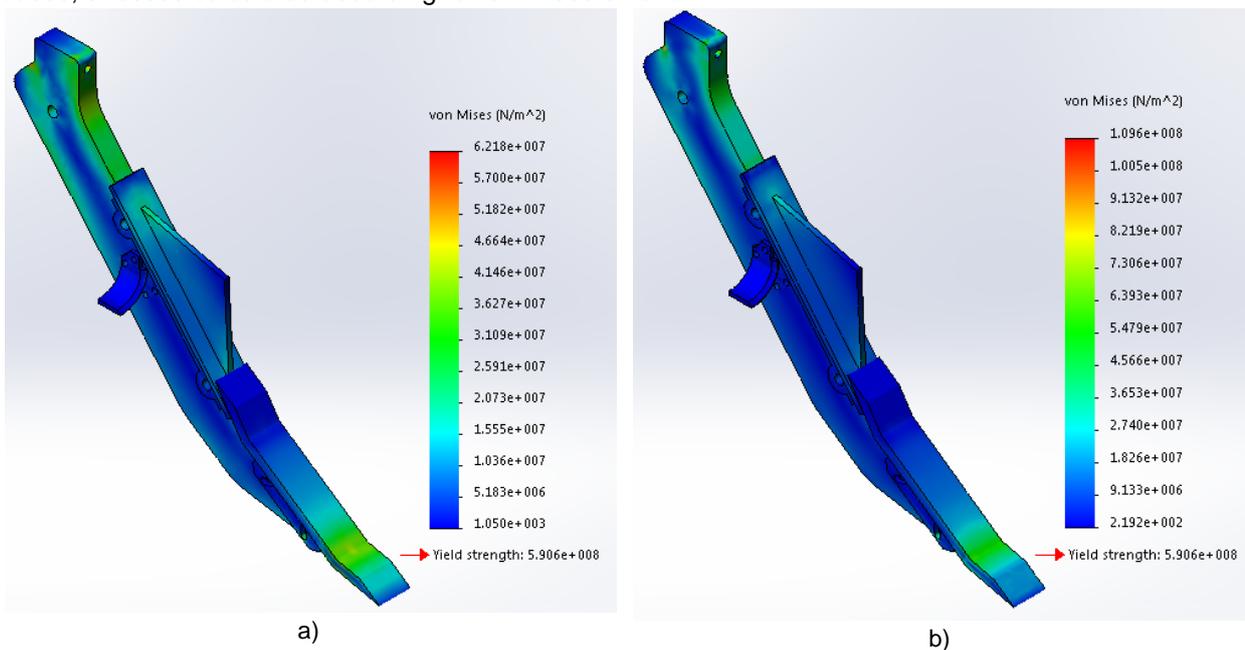


Fig. 7 - The values of the equivalent stresses of the working part during the two working regimes, according to the von Mises criterion
 a) $a = 0.3\text{ m}$ and $v = 2.777\text{ m/s}$; b) $a = 0.4\text{ m}$ and $v = 2.222\text{ m/s}$

Analysing the figure, it can be observed that tension concentrating points appear in the structure of the working part. They are located in the area in which the shear bolt is mounted for the first working mode or behind the holding area of the working part for the second working mode (see fig. 8). The values of the von Mises equivalent stresses created at these points are $6.218 \cdot 10^7\text{ Pa}$ for working regime 1 and $1.096 \cdot 10^8\text{ Pa}$ for the working regime 2. Ignoring these points, it can be seen that the maximum stress in the working part for the two working regimes is around $3 \cdot 10^7\text{ Pa}$.

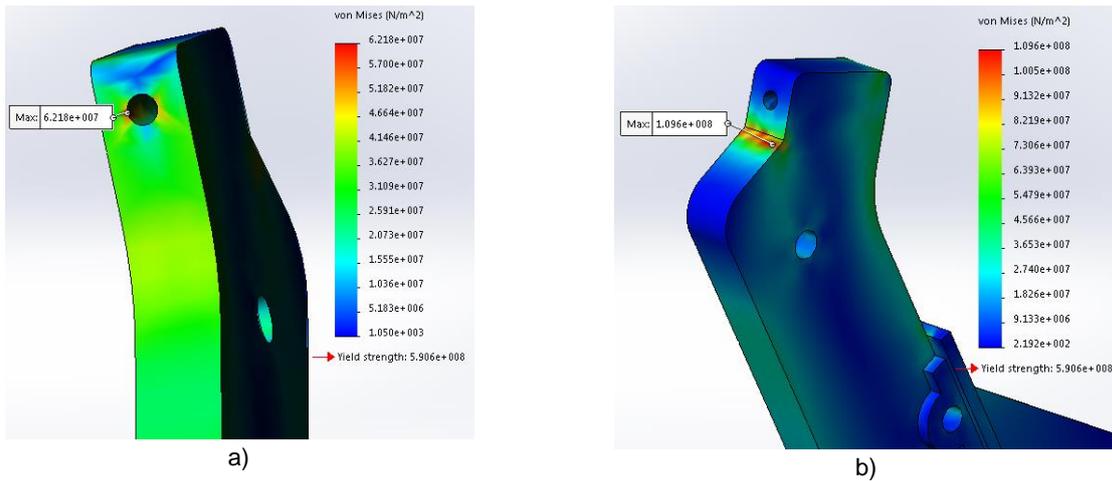


Fig. 8 - The stress concentration points in the working part during the two working regimes
 a) $a = 0.3\text{ m}$ and $v = 2.777\text{ m/s}$; b) $a = 0.4\text{ m}$ and $v = 2.222\text{ m/s}$

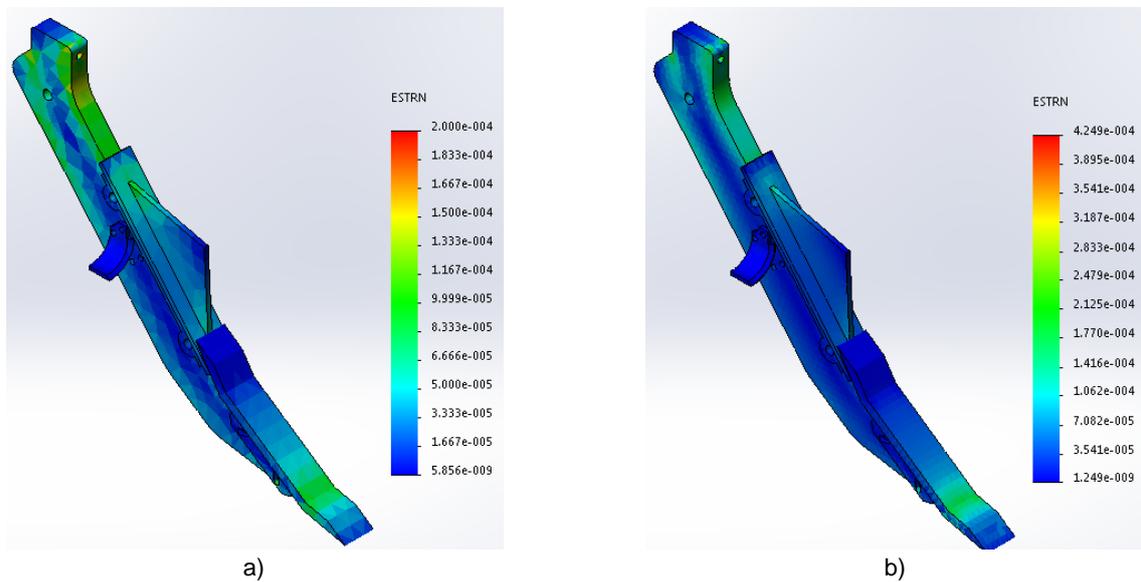


Fig. 9 - The values of the equivalent deformations that appeared in the working part during the two working regimes
 a) $a = 0.3\text{ m}$ and $v = 2.777\text{ m/s}$; b) $a = 0.4\text{ m}$ and $v = 2.222\text{ m/s}$

Analysing figure 9, we can observe the values of equivalent deformations that appear in the working part following the stress to which it is subjected.

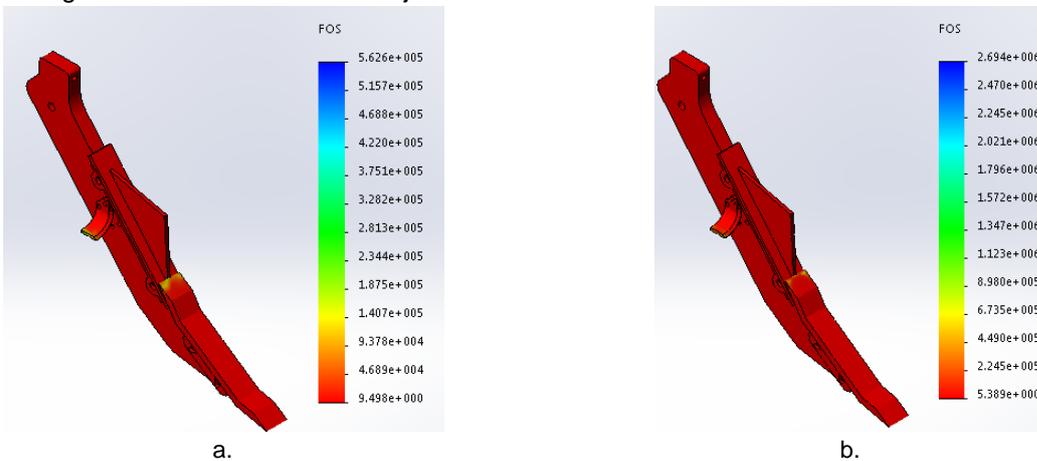


Fig. 10 - Variation of the safety coefficient in the working part during the two working regimes
 a) $a = 0.3\text{ m}$ and $v = 2.777\text{ m/s}$; b) $a = 0.4\text{ m}$ and $v = 2.222\text{ m/s}$

So, the maximum equivalent deformation arises at the same stress concentration points, the deformation value being $2 \cdot 10^{-4}$ for the first working regime 1 and $4.25 \cdot 10^{-4}$ for the second working regime, while the minimum equivalent deformations have values below $5 \cdot 10^{-9}$.

In fig. 10 the oscillation of the safety coefficient in the working part for the two working regimes is presented. The safety factor is calculated relatively to the yield strength stress and varies on the structure border in the two simulations. Between the minimum values of the safety factor in the two variants of simulations is transmitted approximately the same difference, as between the maximum values of the equivalent specific deformation and the equivalent stress.

CONCLUSIONS

The minimum value of the safety coefficient is 9.498, respectively 5.389. For agricultural machines intended for ploughing, the coefficient of safety takes values between 1.8 and 2.2. Thus, it can be said that this subsoil is either oversized or it is made to work in much heavier conditions than those provided by this study, or to withstand even at overload (impact with tree roots, stones etc.).

From the analysis it also resulted that in the structure of the working part there appear stress concentration points, located in the area in which the shear bolt is mounted for the first working regime or behind the holding area of the working part for the second working regime. The values of the equivalent stresses calculated with the von Mises criterion at these points are $6.218 \cdot 10^7$ Pa for working regime 1 and of $1.096 \cdot 10^8$ Pa for working regime 2, values quite close to the breaking limit of the chosen material.

The results presented in the paper can be useful to designers and manufacturers in the agricultural machinery industry, but not only.

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