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ASPECTS OF THE THEORETICAL RESEARCH ON THE INTERACTION BETWEEN WORK ORGANS AND SOIL

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Abstract: *This paper presents a theoretical study on the interaction between working organs of the soil working machines and soil. The study considers that the choice of optimal dimensions of the working organ is closely related to the physical-mechanical properties of the soil. Depending on these properties, to the functional dependence of the parameters it is necessary to add additional parameters that qualitatively characterize the soil. The modeling of the interaction process between the working organs and the soil is based on the theory of equilibrium at the limit that implies the existence of functional bonds established between the parameters characterizing the mechanical properties of the soil. Because real soils have different physical-mechanical properties and functional dependencies between their properties are usually unknown, theoretical research takes into account soils with simplified (ideal) characteristics.*

Keywords: *interaction, working organ, tensions and deformations, strength force.*

1. Introduction

The study of the strains and deformations that develop in a mass of soil under the action of external forces is done by means of soil mechanics. In the case of the soil-working system of agricultural machinery, the phenomena are of a dynamic nature characterized by the fact that the loads have a short duration of application and are variable over time, the surfaces to which they apply are reduced and the soil layer on which they act must have a low humidity [1]. As a result, the theoretical study of the state of strains and deformations that develop in the mass of soil under the action of an external load must take into account a number of particularities such as: the thickness of the soil layer being processed, the mode and duration of soil load application, soil structure, soil moisture, load area etc. [2].

Soils are non-homogeneous and anisotropic materials. As a result, the physical-mechanical properties in

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different directions show great variability. The three-phase soil composition changes continuously under the action of atmospheric factors in terms of the water and air content of its mass, temporarily altering within wide limits its physical-mechanical properties [4], [6]. For the study of soils of a certain structural class (sandy, clay etc.), it can be assumed on the basis of approximations that the soils are homogeneous and isotropic materials, thus the theoretical study of the phenomenon that unfolds in their mass under the action of external tasks is can be performed on the basis of classical mechanics laws (the study of the demands and deformations of the soil mass using Hooke's law) [1], [2].

In the case of soil, compared to other materials, the particles constituting the solid part of it are interconnected, the deformation resistance being determined by the bonds between the particles and not by the actual mechanical strength of the particles [6], [7]. Under the action of external forces, soil deformation occurs with shape modification, with or without volume change. Changing the shape of the soil is due in particular to the change in the void volume between the particles. The resistance that soil opposes under the action of external loads depends on their physical and physical-mechanical properties [2], [6]. Wet and porous soils show a low resistance to external loads, with large deformations even at low intensity mechanical actions. Soil is a material presenting itself simultaneously, in certain proportions, with properties of elasticity, viscosity and plasticity, defined as essential rheological properties [1], [2], [7].

The porous structure of the soil, the speed and the duration of application of external loads determine the difference in rheological behavior. Depending on the rheological properties of the component elements, an external load produces in the soil mass different elastic or plastic deformations, resulting in a worsening of the initial structure, altering the water and air regime in the soil mass, which results in a decrease of the soil porosity (compaction) [3], [5], [7].

The action of external loads on the soil occurs in two stages [1], [3]:

- In the first stage there is a deformation of the soil, a phenomenon characterized by the proximity of the component particles, without the relative displacement of the particles;
- In the second stage, if the ground mass efforts exceed the breaking strength, the internal structure is destroyed and the phenomenon of the relative movement of the soil particles occurs.

For the working organs of agricultural machinery, the following aspects are characteristic: the high speed and the short duration of application of the external loads, the relatively small surfaces that are required, the soil layer is generally unsaturated with water [1], [4], [5].

The theoretical analysis of the slow or rapid phenomena occurring in the mass of the soil, under the action of different external loads, is based on rheological models that highlight certain soil properties, specific to the different pedological categories [3], [6].

2. Material and Method

According to the theory of soil mechanics, depending on the behavior under the action of external loads, the soils can be adhesive or non-adhesive. The study of non-adhesive soils is characterized by the sliding and rolling of soil particles. Resistance of non-adhesive soils is characterized by friction, sliding and rolling of particles [3], [7]. The simplest representation of forces that are formed in the plane of displacement is given by the relation:

$$T=\mu N \quad (1)$$

where: μ = coefficient of internal friction.

If a soil particle (Figure 1) is subjected to the compression forces on perpendicular planes, different cutting surfaces result in which perpendicular and displacement forces act [3].

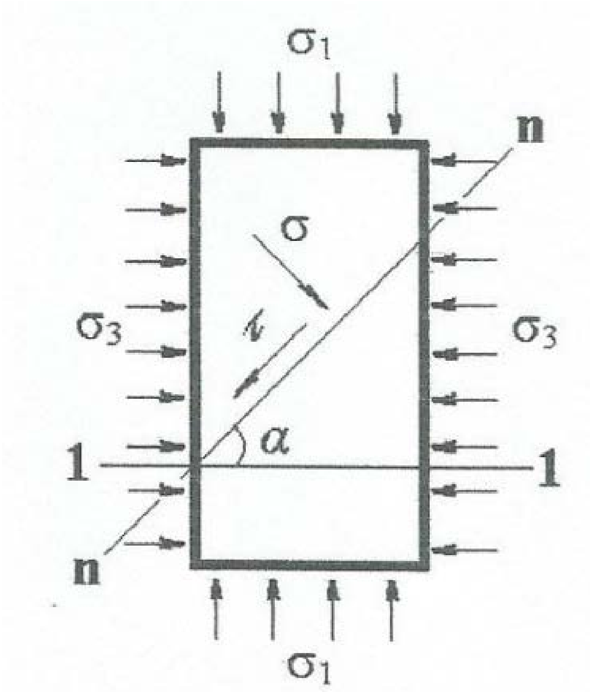

Fig. 1. *Tension distribution (3)*

As a result, in the vertical plane there acts the main tension σ_1 and in the horizontal plane there is tension σ_3. In the nn section under the angle α, due to the basic stresses σ_1 and σ_3, in the section plane the tangential tension ʋ and the normal tension σ appear. These tensions can be determined by the equilibrium condition of the prism formed by planes nn and 1-1 [3], [7].

If the geometrical dimensions of the prism are denoted by ds in the section nn, dx in the horizontal plane and dz in the vertical plane the equilibrium conditions can be determined [3], [7]. The values of the tangential and normal stresses ʋ and σ, in any ground cutting plan under the action of the main stresses σ_1 and σ_3, can be determined with the relations [3]:

$$\sigma = \frac{1}{2}(\sigma_1+\sigma_3) + \frac{1}{2}(\sigma_1-\sigma_3)\cos 2\alpha \qquad (2)$$

$$\tau = \frac{1}{2}(\sigma_1-\sigma_3)\sin 2\alpha \qquad (3)$$

If in a XOY coordination system the values of the normal stresses determined by equation (2) are represented on the axis OX, and on the axis OY the values of the tangential stresses determined by the equation (3), for different values of α, then the points obtained on the graphic form a circle [1], [3], [7].

The theory of equilibrium is limited to the adhesive and non-adherent media of soil mechanics and it is very difficult because solving it with the help of theories of elasticity and plasticity would be very cumbersome. That is why to solve the problem the Coulomb - Mohr theory is used, which aims to determine the forces acting on the soil working organ from the part of the soil and the direction of the soil sliding surfaces in the equilibrium limit state. According to this theory, the tangential stresses on the surfaces of the horizontal sections are null and only the normal stresses are taken into account [3], [4], [6], [7].

Based on Coulomb-Mohr theory, in the process of interaction between the working organ and the ground, the main stress plane σ_p is displaced from the edge of the working organ with the external friction angle ϕ. According to the Mohr stress diagram, the inclination of the travel plan to the vertical is given by the angle λ = =π/4 +ϕ´/2 [1], [2], [3], [7].

Figure 2 shows the value of the main tension [3] :

$$\sigma_p = G_n \frac{1 + \mu \mathrm{tg}\lambda}{(1 - \varphi\mu)\mathrm{tg}\lambda} \qquad (4)$$

where:

σ_p – main tension;

ϕ- tgμ - angle of internal friction;

G_n – the weight of the ground prism.

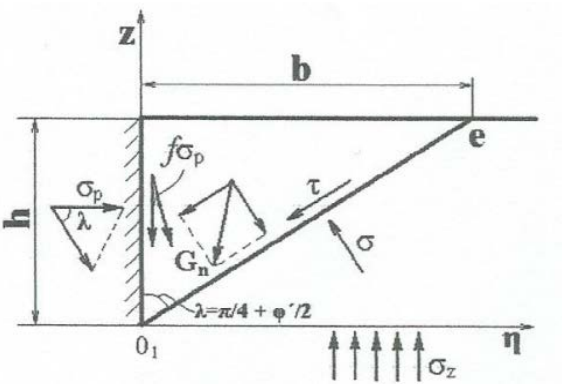

Fig. 2. *Inclination of the movement plan (3)*

This equation presents a functional link between the pressure exerted by the working organ and the mechanical parameters of the soil. By moving the working organ, the soil prism performed moves not only laterally, but also vertically [3], [4]. Continuous movement of the prism under an angle λ to the horizontal leads to the formation of a heap in front of the working organ. Thus, to the weight of the prism Gn is the weight of the heap Gx is added. Considering this weight, the main tension will have the following form [3]:

$$\sigma_p = (G_n + G_x)(1 + \mu\, tg\, \lambda)/(1 - \varphi\, \mu)\, tg\, \lambda \quad (5)$$

By replacing in the equation (5) the total mass of soil interacting with the working organ one can obtain:

$$\sigma_p = \gamma\, hl \cdot \left[0{,}5 htg\lambda + a \frac{\cos\varphi}{\cos(\beta + \varphi)} \right] \cdot \frac{1 + \mu tg\lambda}{(1 - \varphi\mu) tg\lambda} \quad (6)$$

where:
γ – soil specific mass;
h – depth of work (m);
l – length of the working organ (m);
a – working width (m);
β – angle of lateral inclination (°).

Since this equation represents all the actions that the working organ exerts on the soil, it can be said that in absolute value the main stressσ_p is equal to the force of the soil reaction on the working organ [3], [7]:

$$\sigma_p = R_0 \quad (7)$$

where R_0 - the force of soil reaction on the working organ that acts in the same plane as the main tension, but in the opposite direction [3], [4], [7].

The adhesion force for the adhesive soil on the working organ is determined if the ideal tangential tension acting on the displacement plane is added theideal adhesion parameter "C" [3], [7]. Thus we can obtain:

$$R_0 = k \cdot V + 2\, C\, \gamma\, S_r \quad (8)$$

where:

$\gamma = \dfrac{\cos\varphi}{\cos\mu}$;
V – volume of prism and heap;
S_r – the active area of the working organ.

The deformation soil resistance given by the equation (8) is considered to be independent of velocity, but from the time of movement of the working organ, the soil in its action zone passes from the state of rest in the state of motion, obtaining the final velocity [3], [5], [7]. The law of motion determined by the change of the velocity value in the time unit can be expressed by the relation [3]:

$$R_V = \frac{d(mV\eta(}{dt} = \frac{dV\eta}{dt} m + \frac{dm}{dt} V\eta \quad (9)$$

If the speed of movement of the working organ is constant (V= const.), then the final speed of the soil particles displaced by the working organ will be constant (Vη = const). In this case, the first term of the relationship that determines the energy consumption needed to change the velocity of the soil mass is equal to zero and the law of variation of the movement becomes [3]:

$$R_v = V_\eta \frac{dm}{dt} \qquad (10)$$

The R_v reaction as a function of the work organ speed gives rise to an additional tension σ_v in the main tension plane. The principle of relative movement is used to determine this tension: the working organ is fixed and the soil environment moves [4].

Since $R = R_O + Rv$, the total reaction of the soil on the working organ that moves into the non-adhesive soil will be [3], [5]:

$$R = kV + \varepsilon SV^2 \qquad (11)$$

where:

k - soil resistance coefficient (N/m^2);

ε - coefficient which takes into account the increase of the travel speed ($N{\cdot}s^2/m^4$) and for adhesive soil it will be:

$$R = kV + 2CvS_r + \varepsilon SV^2 \qquad (12)$$

where:

C – proportionality coefficient;

v– movement speed (m/s).

The reaction of the soil on the working organ can be presented as a result of two forces: normal pressure N and frictional force F (Figure 3).

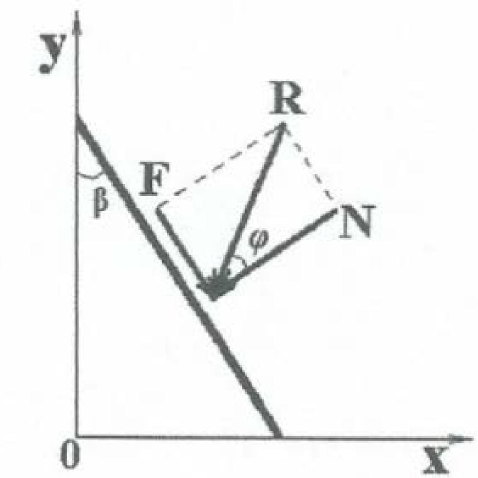

Fig. 3. *The reaction of the soil on the working organ*

The analytical determination of normal pressure and of frictional force can be done with the help of the oscillograph and the angle of friction can be determined ϕ, which in its turn gives the possibility of checking the theoretical formulas [3], [4], [6], [7].

From Figure 3 it results that:

$$N = R\cos\varphi \qquad (13)$$

$$F = N\,tg\varphi = R\sin\varphi \qquad (14)$$

Entering the value of R determined by the relations (11) and (12) in equations (13) and (14), the values of the forces sought are obtained.

Traction force P is determined by the projection of the soil resistance force on the"y"-axis. Thus, the drive force (traction) is determined with the relation [3], [7]:

$$P = \mu(kV+2C\gamma S_r+\varepsilon Sv^{2)} \quad (15)$$

where:
μ = 2sin(β+ϕ) – coefficient;
S – surface of processed soil.
The partial solving of this relationship is:

- For non-adhesive soil, when C=0:

$$P = \mu(kV+\varepsilon Sv^{2)} \quad (16)$$

- For non-adhesive soil, if C=0 and v→0:

$$P_0 = \mu kV \quad (17)$$

- For adhesive environments when v→0:

$$P_0 = \mu(kV + 2C\gamma S_r) \quad (18)$$

3. Results and Discussions

The analysis of the components that influence the resistance opposed by the working organs in the soil processing endeavor and which depend on its geometric parameters shows that with the increase of the turning angle, keeping the front projection of the work body constant, the value of the resistance decreases. The reason for this is the decrease in the length of the working area of the working organ (1), (3), (4), (7). From equation (15) it follows that, depending on the parameters of the working organ and the working regime, force "P" is a function of five independent variables: P= f (a, l, h, β, v) [3], [7], where: a – working width (m); l – the length of the workpiece (m); h – depth of work (m); β – angle of lateral inclination (°); v – speed of travel (m/s).

Thus,

$$P_{(a)} = A_0 + B_0 \cdot a \quad (19)$$

$$P_{(l)} = A_1 + B_1 \cdot l \quad (20)$$

$$P_{(h)} = A_2 h + B_2 \cdot h^2 \quad (21)$$

$$P_{(\beta)} = A_3 \sin\alpha + B_3 \sin\beta \cdot \mathrm{tg}\,\alpha \quad (22)$$

$$P_{(v)} = A_4 + B_4 \cdot v^2 \quad (23)$$

where A and B are the coefficients of independent variables, and the angle α = β + ϕ

4. Conclusions

The models used to predict interaction forces of soil-work organ, are based on the Mohr-Coulumb soil mechanics. Mathematical models determine the average result force, but in practice the resistance forces vary cyclically with an amplitude equal to 20% of the average value, especially for narrow work organs.

The force of traction resistance of any unmanned working organ intended for work on the soil is dependent on work depth, travel speed, workpiece width, work organ geometry and physical and mechanical soil properties (apparent specific density and penetration resistance).

Rheology and fluid flowing, the soil can be considered a viscous plastic material, and its mechanical behavior during the processing stage can be studied from a fluid flow perspective with non-Newtonian behavior.

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