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Analytical model of soil pulverization and tillage tools

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Abstract

The paper deals with the pulverization (fracture) model that is not based on soil elastic properties but on the physical processes of the wedge interaction with soil. The presented model agrees with the experimental data better than other models, including those based on soil elastic properties, and the tests of flat tillage tools with a variable cutting angle have proved this.

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Keywords: fracture model, tractive resistance, soil pulverization, two-sided wedge, interaction, optimal parameters.

1. Introduction

Up to the present moment, there are no universally accepted models of soil pulverization. A significant number of well-known soil pulverization (fracture) models resort to fracture patters of an elastic body. Numerous attempts of using the investigation methods of elastic materials for soil pulverization have not yielded practical results yet, since the relationship between the force acting on the soil and the soil deformation is the function of the soil condition. Therefore, the use of the mathematical apparatus for fracturing elastic bodies in its classical form when designing working bodies is ineffective. Thus, this paper is concerned with one of feasible approaches to investigating the process of soil pulverization (fracture) with tillage tools.

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2. Metodology

The basics of the approach are:

- the pulverization of the soil and its elements happens when the acting force exceeds the soil resistance force;
- the value and direction of the acting force can be determined through analysing the tillage tool interaction with the soil;
- the soil resistance force can be estimated on the basis of its aggregate-size distribution and humidity at the time of tillage.

Now let's consider some of the elements of the pulverization process exemplified with a two-sided wedge (Figure 1).

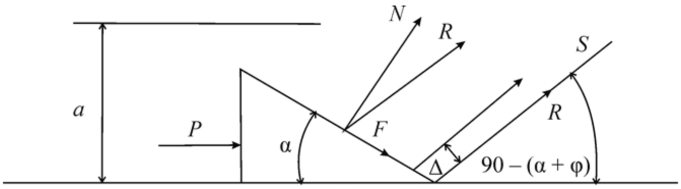

Figure 1 The soil fracture with a two-sided wedge

When moving in the soil the wedge interacts with the soil normal, declined at a friction angle of the soil movement on the wedge surface. In this direction the wedge moves the soil along the plane and the soil area is:

$$S = \frac{ab}{\sin(90-(\alpha+\varphi))} = \frac{ab}{\cos(\alpha+\varphi)}, \qquad (1)$$

where S is the pulverization plane of the soil;
a is the depth of the wedge movement;
α is the two-sided wedge angle;
φ is the friction angle when the soil slides on the wedge;
b is the wedge width.

And the value of the force R should be equal to:

$$R = \frac{\mu ab}{\cos(\alpha+\varphi)}, \qquad (2)$$

where μ is the friction coefficient of the soil particles over the area S.

This coefficient, of course, can hardly be considered as the ultimate soil shearing resistance τ with a number of assumptions.

The action of the force R can manifest itself only when a soil layer of the Δ thickness is formed on the wedge. The wedge penetrates into the soil without breaking it up until the thickness of the soil layer becomes Δ. The value of the layer thickness can be determined from the condition:

$$R = \Delta b\sigma, \qquad (3)$$

where σ is the ultimate normal stress on the layer.

Solving the equations (2) and (3) together we have:

$$\Delta = \frac{a\tau}{\sigma\cos(\alpha+\varphi)} \quad \text{or} \quad \Delta = \frac{\mu a}{\sigma\cos(\alpha+\varphi)}, \qquad (4)$$

Figure 2 shows the dependence of the pulverization element thickness Δ on the setting angle of the wedge to the furrow bottom, provided: $\sigma = 10\tau$.

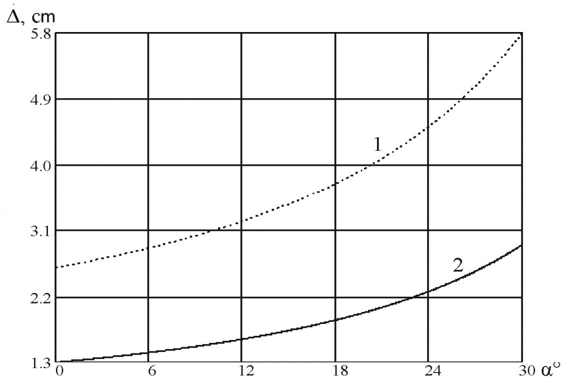

Figure 2 The thickness of the soil fracture elements depending on the setting wedge angle to the furrow bottom (σ_c=10τ; 1 – *a* = 20 ; 2 – *a* = 10 cm)

Applying the value Δ to the equation 3, we get:

$$R = \frac{\mu ab}{\cos(\alpha + \varphi)} \quad \text{or} \quad R = \frac{\tau ab}{\cos(\alpha + \varphi)}, \qquad (5)$$

The power of the tractive resistance *P* is determined by the obtained fracture force *R* and the friction force of the soil movement on the wedge at the pulverization point *F* when ignoring the efforts necessary to move the obtained soil layer on the wedge of the length *L* (Figure 3, 4):

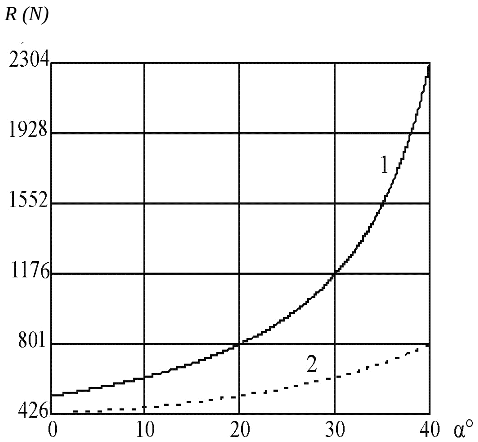

Figure 3 The power on the wedge when pulverizing the soil of the thickness Δ:
1 – the depth of the wedge movement 0,2 m;
2 – the depth of the wedge movement 0,1 m

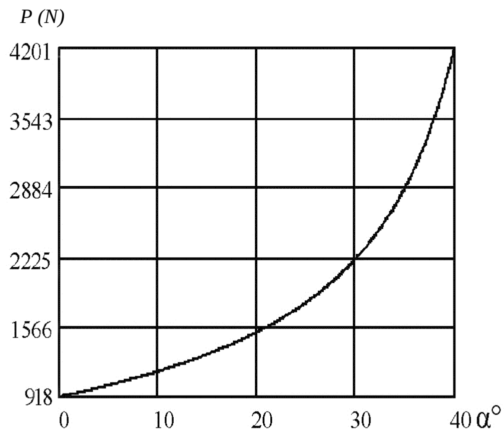

Figure 4 The wedge resistance force when pulverizing the soil μ=40000N/m^2, *a*=0,1*m*, *b*=0,1*m*, φ=40°

$$P = R\cos(90 - (\alpha + \varphi)) + F\cos\alpha, \qquad (6)$$

where *F* is the friction force when moving the soil on the wedge at the pulverization point of the continent layer:

$$F = N\mathrm{tg}\varphi, \qquad (7)$$

where φ is the friction angle,

N is the force of the normal pressure on the soil surface when pulverization the continent soil:

$$N = \frac{R}{\cos\varphi} = \frac{\mu ab}{\cos\varphi\cos(\alpha+\varphi)} . \quad (8)$$

When applying *F* to the equation 6 we get:

$$P = R\left(\sin(\alpha+\varphi) + \frac{\cos\alpha \,\mathrm{tg}\varphi}{\cos\varphi}\right) . \quad (9)$$

The numerical values of the component of the tractive resistance force (*R* and *F*) are shown in Figure 5.

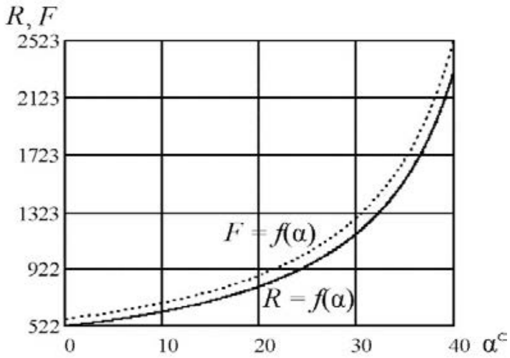

Figure 5 The components of the wedge tractive resistance force when pulverizing the soil (*F* is the upper curve, *R* is the low curve: μ=4000N/m^2; a=0,1m; b=0,1m; φ=40°)

3. Results

These theoretical findings were applied to the operating parts of flat-cutting and mouldboard ploughs, with the results of laboratory and experimental tests being presented below.

Thus, the foregoing caused to put forward the following scientific hypothesis: the variable cutting angle along the blade length improves the soil layer pulverization. To confirm this scientific hypothesis the above mentioned theoretical and laboratory-industrial experiments were conducted.

The laboratory tests needed a specially made soil channel and a set of two-sided wedges that differ from each other in cutting edge angles set to the furrow bottom. Moreover, the tests were carried out in different physical and mechanical properties (typical chernozem, sand, peas, clay), with the influence of the variable cutting angle on the bending of clay, plasticine and wet chernozem being determined.

The laboratory tests proved the following:

- despite the differences in physico-mechanical properties and the formation appearance of the outer layer, all environments when interacting with the wedge have some common characteristics dependant on the wedge parameters,
- the blade with a variable cutting angle causes the stress state in the soil layer more than the blade with a constant cutting angle.

As a result, there were obtained [1] mathematical formula for determining the equivalent stress (the stress state) produced by a blade with a variable and constant cutting angle.

$$\frac{\sigma^{III}}{\sigma^{II}} = \frac{1}{2} + \frac{1}{2}\sqrt{1 + 1{,}5\rho^2\left(\frac{\Delta\varepsilon}{l}\right)^2} , \quad (10)$$

where σ^{III} is the stress state caused with a blade with a varying cutting angle in the soil layer;
σ^{II} is the stress state caused with a blade with a constant cutting angle in the soil layer;
ρ is the radius of the soil layer bending;
Δε is the intensity of the cutting angle changing along the length of the blade (in Δε experiments varied from 200 to 450);
l is the blade length.

When analyzing the results it can be noted that the wedge with a variable cutting angle causes a greater stress state in the soil layer than the wedge with a constant cutting angle. When the pulverization is in proportion to stresses, the wedge with a variable cutting angle is proved to ensure a better pulverization.

The theoretical and laboratory studies have helped to create the operating parts of cultivators and subsurface ploughs with variable cutting angles.

The nature of stresses that occur in the soil layer varies. When the soil is tilled with a machine with a constant angle along the cutting ploughshare, the stress state occurs because of bending deformation, and when the soil is tilled with a machine with a variable angle, the stress state is caused by bending-torsion deformation.

The experimental data on pulverization and tractive resistance prove the validity of our scientific hypothesis (Figure 6).

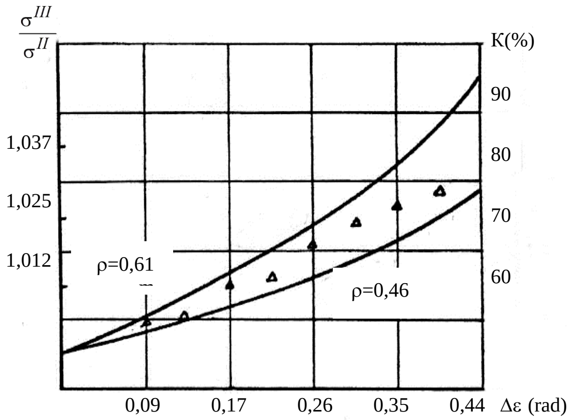

Figure 6 The influence of the intensity of changing cutting angles along the ploughshare (Δε) on the equivalent stress and the soil layer pulverization: Δ is the experimental data concerning the tilled soil layer pulverization

Thus, the model of soil pulverization can be considered to be in good agreement with physical processes of the wedge interaction with soil, and the calculated data in Figures 2-5 correspond to the experimental ones obtained by many scientists in Russia and abroad [2, 3, 4, 5, 6, 7, 8, 9].

The presented models with the experimental data is much more convergent as compared with others, including those based on the elastic properties of soil.

To obtain the necessary quality of soil pulverization this paper offers operating parts for cultivator-subsurface ploughs with variable cutting angles.

4. Conclusions.

The experimental data prove operating parts for cultivator-subsurface-ploughs with variable cutting angles along the ploughshare to cause a 20-50% better soil pulverization than traditionally produced ones, with the economic effect of the former operating parts to be 200-1300 roubles per 1 ha of cultivated area higher as compared with the latter ones.

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