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DEVELOPMENT OF A PHYSICAL MODEL AND DETERMINATION OF SIMILARITY COEFFICIENTS OF A SPATIALLY ORIENTED KNIFE OF A BULLDOZER BLADE

This paper considers the creation of a physical model of an equipment for cutting soils with a spatially oriented knife of a bulldozer blade for experimental studies. In order to study the process of interaction between the working body and the working environment, it is necessary to conduct experimental studies, for which, as a rule, natural objects of research or their models are used. Physical modelling preserves the physical nature of the phenomena, but changes their scale. Using the similarity theory and physical modelling, the conditions of similarity of the equipment for cutting soils with a spatially oriented knife of a bulldozer blade are determined, in which the interaction of the working body and the working environment is described by a power equation taking into account their parameters. In this case, the parameters of the natural process of interaction between the working body and the working environment are written through the parameters of the physical model and similarity coefficients. As a result of dividing the corresponding terms of the force equations of the natural equipment and the model by each other, a system of two equations was obtained that links six unknown values of the similarity coefficients. The obtained values of the similarity coefficients made it possible to build a physical model of the installation for cutting soil with a spatially oriented knife of a bulldozer blade, which is similar to the natural installation for cutting soil with a spatially oriented knife of a bulldozer blade. As a physical model of the equipment, taking into account the similarity coefficients and the envisaged research tasks, the dynamometric stand for registering the force load of the author's design of KNUBA was modified to study the process of cutting soils with a spatially oriented knife of a bulldozer blade, which allows for full-fledged experimental studies, taking into account all the existing factors of interaction between the working medium and the working body during cutting. It is proposed to use paraffin wax as a working environment and a steel model of a spatially oriented knife as a working body.

Key words: *installation, physical model, cutting, working body, environment, modelling, similarity coefficients.*

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ПОБУДОВА ФІЗИЧНОЇ МОДЕЛІ ТА ВИЗНАЧЕННЯ КОЕФІЦІЄНТІВ ПОДІБНОСТІ ПРОСТОРОВО ОРІЄНТОВАНОГО НОЖА ВІДВАЛУ БУЛЬДОЗЕРА

У даній роботі розглянуто створення фізичної моделі установки для різання ґрунтів просторово орієнтованим ножем відвалу бульдозера, для проведення експериментальних досліджень. З метою дослідження процесу взаємодії робочого органу з робочим середовищем виникає необхідність проведення експериментальних досліджень, для яких, як правило, використовуються натурні об'єкти дослідження або їх моделі. При фізичному моделюванні зберігається фізична природа явищ, але змінюється їх масштаб. Використовуючи теорему подібності та фізичне моделювання, визначено умови подібності установки для різання ґрунтів просторово орієнтованим ножем відвалу бульдозера, в якій взаємодія робочого органу та робочого середовища описується силовим рівнянням із врахуванням їх параметрів. При цьому параметри натурального процесу взаємодії робочого органу та робочого середовища записано через параметри фізичної моделі та коефіцієнти подібності. В результаті ділення відповідних доданків силових рівнянь натурної установки та моделі між собою отримано систему з двох рівнянь, яка зв'язує між собою шість невідомих величин коефіцієнтів подібності. Отримані значення коефіцієнтів подібності дали можливість побудувати фізичну модель установки для різання ґрунтів просторово орієнтованим ножем відвалу бульдозера, що подібна натурній установці для різання ґрунтів просторово орієнтованим ножем відвалу бульдозера. В якості фізичної моделі установки з врахуванням коефіцієнтів подібності та передбачених задач досліджень було доопрацьовано динамометричний стенд реєстрації силового навантаження авторської конструкції КНУБА для дослідження процесу різання ґрунтів просторово орієнтованим ножем відвалу бульдозера, що дозволяє провести повноцінні експериментальні дослідження з врахуванням всіх чинних факторів взаємодії робочого середовища та робочого органу під час різання. В якості робочого середовища запропоновано використання парафін, а в якості робочого органу – стальну модель просторово орієнтованого ножа.

Ключові слова: *установка, фізична модель, різання, робочий орган, середовище, моделювання, коефіцієнти подібності.*

Formulation of the problem

For experimental research, as a rule, full-scale research objects and their models are used [1]. In a full-scale experiment, the means of experimental research interact directly with the object of research, and in a model experiment – with its modelled prototype.

When conducting model experimental research, the model acts as a means of experimental research and a direct object of research [2–4].

Analysis of general research and publications

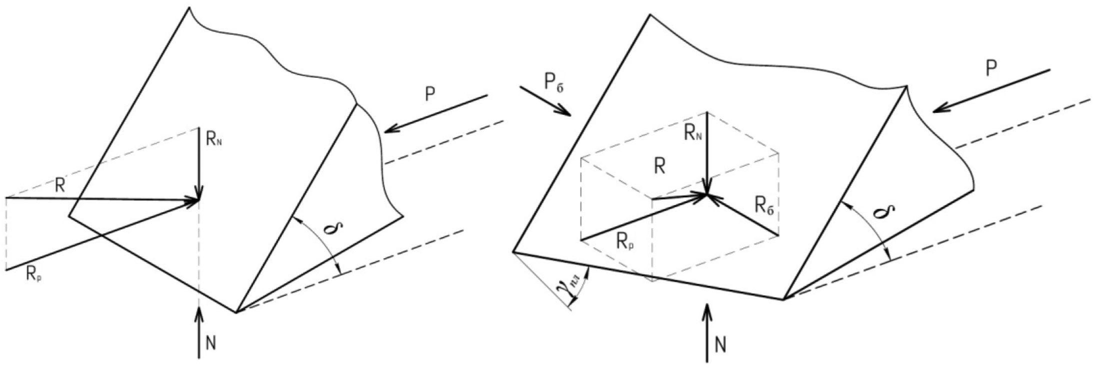
Nowadays, the creation of a real working body for experimental research would require a significant amount of time and money. Given this, the task is to create a physical model of this working body and conduct full-fledged experimental studies on it.

As the criteria of similarity for the construction of a physical model (Fig. 1), dimensionless complexes are used, which are the ratio of the corresponding components of the differential equations of the real object and the model.

The methodology for modelling the working processes of soil destruction is based on the theory of similarity.

The conditions for physical modelling of the working process of soil destruction stipulate that: the defining criteria for the similarity of the soil destruction process for the model and the original should be the same; the physical parameters of the system of differential equations describing the working process compiled for the model and the original should be proportional; the process of interaction of the working tool with the environment in the model and the original should belong to the same class of phenomena and be described by the same system of differential equations; the model and the original of the working tool and the system.

The working hypothesis is based on the fact that the combination of the positive effects of reducing the energy intensity of destruction by a spatially oriented knife cutting will allow for an overall reduction in the energy intensity of soil destruction by a blade. in our opinion, this should ensure the cutting of the soil and its easy removal from the development zone. Thus, reducing the resistance that occurs during the operation of the bulldozer and increasing its productivity, as well as expanding the scope of use.



a *b*

Fig. 1. Interaction of the bulldozer blade with the working environment during *a*) rectangular cutting, *b*) oblique cutting (spatially oriented)

After applying the vector of the direction of the cutting force with a spatially oriented knife and determining the plan of movement, it becomes clear that there will be a change in the geometric interaction of the spatially oriented knife with the workpiece, which leads to a change in cutting forces and a change in resistances that depend on the geometric parameters of the knife [5, 6].

Cutting force:

$$P = P_f + P_s + P_{s.c}. \tag{1}$$

Full cutting force for rectangular cutting:

$$P = \varphi m_f bh + 2m_s h^2 + 2m_{s.c} h. \tag{2}$$

The interaction between the spatially oriented knife and the working environment is described by the equation:

$$P = \varphi(\delta)\phi_f m_f bh + \phi_s m_s h^2 + \phi_{s.c} m_{s.c} h. \tag{3}$$

Where b, h – knife width and cutting depth (thickness); m_f – strength coefficient characterising the specific resistances in the frontal part of the cut; m_s – strength coefficient characterising the specific resistances in the lateral extensions; $m_{s.c}$ – strength coefficient characterising the specific resistances along the lateral cut lines; $\varphi(\delta)$ – coefficient that takes into account the effect of the cutting angle δ (at $\delta = 45°$ $\varphi = 1$); φ_f – is a coefficient that takes into account the effect of the angle γ_{pl} of the knife's rotation in the plan view, respectively, of the force P_f; φ_s – is a coefficient that takes into account the effect of the angle γ_{pl} of the knife's rotation in the plan view, respectively, of the force P_s; $\varphi_{s.c}$ – is a coefficient that takes into account the effect of the angle γ_{pl} of the knife's rotation in the plan view, respectively, of the force $P_{s.c}$.

Formation of the research aim

The aim of this study is to determine the similarity coefficients for building a physical model of a spatially oriented knife of the bulldozer blade.

Presentation of the main research material

To comply with the conditions of similarity of the processes occurring in the interaction with the environment of the physical model of the original working body, it is necessary to observe the equality of geometric and dynamic similarity criteria. Let's write the parameters of the natural process through the parameters of the physical model and similarity coefficients

$$P_N = \nu_P \cdot P_M,\quad m_{f.N} = \nu_m \cdot m_{f.M},\quad m_{s.N} = \nu_{m_s} \cdot m_{s.M},\quad m_{s.c.N} = \nu_{m_{s.c.}} \cdot m_{s.c.M},\quad b_N = \nu_b \cdot b_M,\quad h_N = \nu_h \cdot h_M, \tag{4}$$

Where P_N, $m_{f.N}$, $m_{s.N}$, $m_{s.c.N}$, b_N, h_N – parameters of the natural model; P_M, $m_{f.M}$, $m_{s.M}$, $m_{s.c.M}$, b_M, h_M – parameters of the physical model, ν_P, ν_m, ν_{m_s}, $\nu_{m_{s.c}}$, ν_b, ν_h – relevant similarity coefficients.

Then we can write equations similar to equation (3) for the natural process and its model, which have the form:

$$P_N = \varphi(\delta)\varphi_f m_{f.N} b_N h_N + \varphi_s m_{s.N} h_N^2 + \varphi_{s.c} m_{s.c.N} h_N; \tag{5}$$

$$P_M = \varphi(\delta)\varphi_f m_{f_M} b_M h_M + \varphi_s m_{s_M} h_M^2 + \phi_{s.c} m_{s.c_M} h_M. \tag{6}$$

Based on the similarity of the model and the natural process, we divide the corresponding terms of equations (5) and (6) among themselves and write the following relations:

$$\frac{P_N}{P_M} = \frac{\varphi(\delta)\varphi_f m_{f.N} b_N h_N}{\varphi(\delta)\varphi_f m_{f.M} b_M h_M} = \frac{\varphi_s m_{s.N} h_N^2}{\varphi_s m_{s.M} h_M^2} = \frac{\varphi_{s.c} m_{s.c.N} h_N}{\varphi_{s.c} m_{s.c.M} h_M}. \tag{7}$$

Using dependencies (4) for these ratios, we obtain:

$$\frac{\nu_P \cdot P_M}{P_M} = \frac{\varphi(\delta)\cdot\varphi_f \cdot \nu_m \cdot m_{f \cdot M} \cdot \nu_b \cdot b_M \cdot \nu_h \cdot h_M}{\varphi(\delta)\cdot\varphi_f \cdot m_{f \cdot M} \cdot b_M \cdot h_M} = \frac{\varphi_s \cdot \nu_{m_s} \cdot m_{s \cdot M} \cdot \nu_h^2 \cdot h_M^2}{\varphi_s \cdot m_{s \cdot M} \cdot h_M^2} = \frac{\varphi_{s.c} \cdot \nu_{m_{s.c}} \cdot m_{s.c \cdot M} \cdot \nu_h \cdot h_M}{\varphi_{s.c} \cdot m_{s.c \cdot M} \cdot h_M}. \quad (8)$$

According to the similarity theorem, we reduce the expression (8), which results in the following relationship between the similarity coefficients:

$$\nu_P = \nu_m \cdot \nu_b \cdot \nu_h = \nu_{m_s} \cdot \nu_h^2 = \nu_{m_{s.c}} \cdot \nu_h. \quad (9)$$

Dividing all parts of equation (9) by, we obtain the system of equations:

$$\frac{\nu_P}{\nu_P} = 1; \quad \frac{\nu_m \cdot \nu_b \cdot \nu_h}{\nu_P} = 1; \quad \frac{\nu_{m_s} \cdot \nu_h^2}{\nu_P} = 1; \quad \frac{\nu_{m_{s.c}} \cdot \nu_h}{\nu_P} = 1; \quad (10)$$

that connect the six unknown quantities. All values are taken constructively, knowing the physical properties of the soil (Table 1) and the model.

Table 1

Physical and mechanical properties of soils

Soil	m_f, MPa	m_s, MPa	$m_{s.c}$, кN/м	μ	Dimensional characteristics of the destruction zone	
					$k_б$	γ
Marl clay	0,3	0,021	0,4	14°	0,8	30°
Heavy loam	0,15	0,013	1,42	18°	0,85	40°
Argillite	0,25	0,024	5,47	16°	0,9	30°
Paraffin	0,76	0,022	16,25	14°	0,8	36°

Conclusions

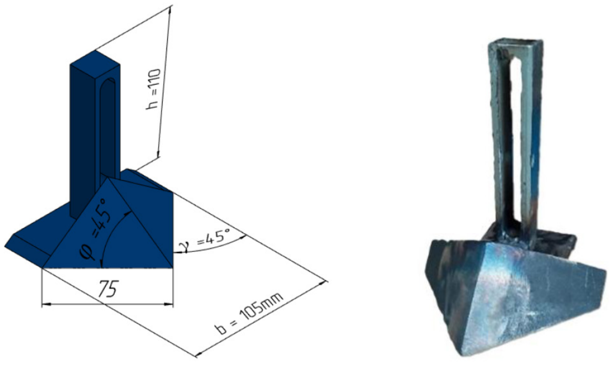
On the basis of the theory of similarity, the similarity coefficients were determined and listed in (Table 2), which were used to calculate the geometric and kinematic parameters of laboratory experiments. This made it possible to design and manufacture laboratory equipment: a stand and a spatially oriented experimental knife.

Table 2

Research equipment parameters

	Categories of soil		
	3	4	5
$\nu_m = \frac{m_{f.N}}{m_{f.M}}$	0,223	0,556	1,067
$\nu_{m.s} = \frac{m_{s.N}}{m_{s.M}}$	0,201	0,5	1,168
$\nu_{m.s.c} = \frac{m_{s.c.N}}{m_{s.c.M}}$	0,23	0,569	1,086
$\nu_h = \sqrt[3]{\frac{\nu_{m.s.c}}{\nu_{m.s}}}$	0,37	0,512	0,82
$\nu_b = \frac{\nu_{m.f} \cdot \nu_h}{\nu_p}$	0,45	0,504	0,77
$\nu_p = \nu_{m.s} \cdot \nu_{h^2}$	0,22	0,544	1,098

In accordance with the obtained similarity coefficients, a model of a spatially oriented knife [9] was created and adapted Fig. 2, and the test bench was improved Fig. 3. To conduct the study, we will use a bench for recording cutting forces [7], which is taken as a prototype and consists of a frame 1, on which a trolley 3 is mounted on guide beams using rollers 2, to which a holder 6 is attached through strain gauges 4 and 5, in which a transmission screw-nut 8 is fixed through the eyelets, the movement of the spatially orientated knife 9 is carried out by an electric motor 10 through a worm gear 7, in turn, the electric motor is controlled by a frequency converter 11. The trolley 3 is equipped with a lifting and



a ***b***

Fig. 2. Spatially oriented knife of a bulldozer blade (*a*) 3D model, (*b*) real model

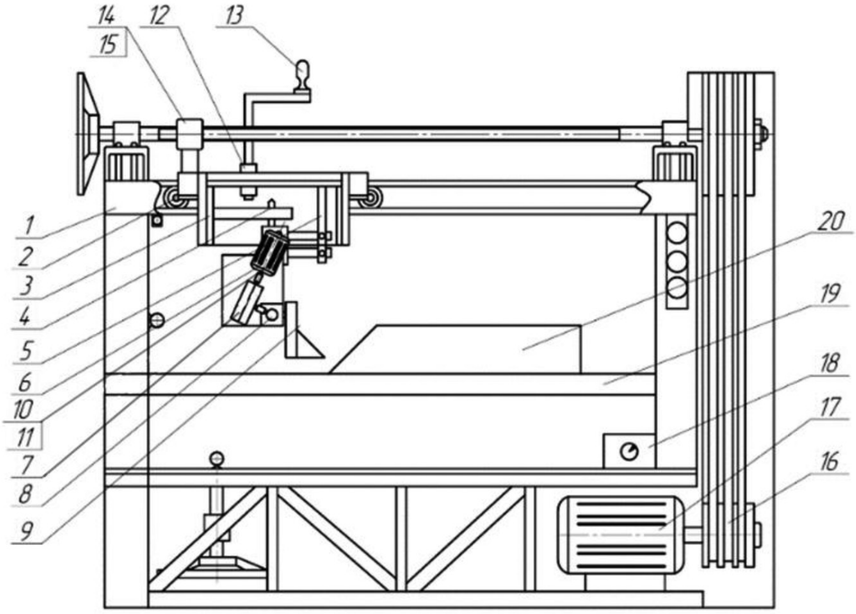


Fig. 3. Schematic of a test bench with a spatially orientated knife

lowering mechanism 12 with a handle 13. The possibility of horizontal movement of the trolley 3 is realised by means of a screw-nut gear 14–15, a V-belt gear 16 and an electric motor 17 connected through a frequency converter 18. The bunker with the test material 20 is fixed on the installation base 19 [8].

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