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THEORETICAL INVESTIGATIONS OF THE PROCESS OF INTERACTION WITH THE ENVIRONMENT OF A BULLDOZER BLADOW WITH VARIABLE GEOMETRY

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The purpose of the work is to determine the rational parameters of a bulldozer blade with variable geometry, which provides an increase in productivity and an expansion of the bulldozer-terrace scope due to its universal adaptability of the cutting knife shape and the blade surface to the types and conditions of work.

The existing studies of the interaction processes with the soil of specialized plough, for the most part, do not take into account specific features and do not allow a reasonable approach to the appointment of the main parameters of the dump with its universal adaptability. For this purpose, studies were carried out on the working process of excavating the soil with a blade of a new universal design, and above all, when digging the soil. The analysis of the ratios influence the central section length to the maximum working width, the inclination angles of the hinges in the longitudinal and transverse planes, and the rotation angle of the side sections on the variable geometric parameters of the blade, which determine its interaction with the ground, is carried out.

At the same time, the theoretical dependences obtained based on the statics provisions of a granular medium with adhesion make it possible to analytically evaluate the dimensions and volume of the drag prism and the horizontal component of the resistance to digging with a blade with variable geometry.

Keywords: blade, bulldozer, blade shape, protruding blade, side blade, digging resistance force, grip width, hinge angle

1 INTRODUCTION

A special place in the system of the efficiency indicators of road construction machines [1-3] is occupied by productivity, which is the basis for determining all other indicators of a higher level. It allows assessing the machine compliance degree with its functional purpose, combining technical parameters with working conditions.

A modern bulldozer is a complex system that includes a number of subsystems united by structural and functional links [4-5]. It is advisable to analyze the efficiency of functioning and optimize the parameters of individual subsystems, taking into account the connections and restrictions imposed by the remaining subsystems, based on the methodology of system analysis [6-9]. One of the most important procedures of this methodology is the choice of a criterion (indicator) for the effectiveness of possible solutions to the problem.

A large number and difficulties in describing many of the parameters and relationships between them lead to the fact that only a part of them is involved in the mathematical modeling of the performance of a bulldozer. Depending on the specific goals, the main parameters of the bulldozer [8, 9], the design features of various subsystems - the working equipment [10, 4, 11, 12], the propulsion and transmission unit, and the propulsion system [13, 14, 15], the system control [13, 16]. To varying degrees, the parameters of the operational background are also reflected - the developed soil, the bearing surface, the construction site, socio-economic and other factors [17, 18], [19-20]. The performance of a bulldozer of a specific design and under specific operating conditions is determined unambiguously when setting the traction-speed mode. In most of the recommended dependencies, the traction force is limited to the nominal, i.e. effort corresponding to the highest efficiency in certain (reference) conditions. With this approach, it is impossible to determine the highest performance in other ground conditions with different traction properties from the reference, as these change the nominal values of traction and operating speed. At the same time, it is quite obvious that a comparison of alternative designs in various conditions should be made taking into account both the features of the interaction of their working bodies with the environment and the traction-speed mode that is optimal for these conditions.

It is important to consider the design and working process of a universal three-section blade with a variable shape (geometry) in the plan, which is the working body of a bulldozer [17, 20]. The design of the blade allows it to be adapted to a wide variety of requirements by pivoting the wing sections relative to the tilted hinges.

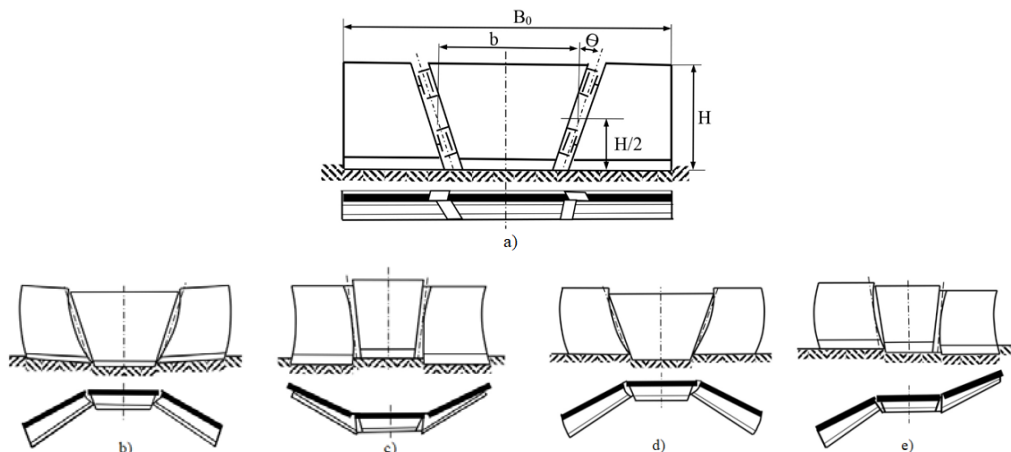


Fig. 16. Schemes for the use of a retractable bulldozer blade with variable geometry for various installations.

Blade installation according to Fig. 1a allows filling the profiling work, the development of embankments and other work, the performance of which is proportional to the width of the capture. When the blade is installed with the side sections turned forward (according to Fig. 1b), the cutting edges of the side knives are skewed at an angle of up to 90 and the value of the protruding part of the middle knife is on average 3% of the blade height.

When installing the dump according to Fig. 1c, the skew of the side sections knives turned forward is compensated by an increase in the installation angle of the middle section. This installation of the blade allows holding and moving significant volumes of soil over increased distances. The small value of the protruding part of the middle knife, up to 2-3% of the blade height, provides additional undercutting, compensating for the loss of soil into the side rollers.

Rotation of the side sections back (Fig. 1d), their rotation in opposite directions (Fig. 1, e), as well as the distortion of the side knives, if necessary, can be similarly compensated by changing the installation angle of the middle section.

When installing the dump according to Fig. 1d - with turning the side sections back and according to fig. 1.e - with a turn in opposite directions, the skew of the side knives can be similarly compensated by changing the angle of the middle section.

Thus, the features of the blade system of the blade do not have a significant impact on the quality of such work as laying pioneer tracks, clearing roads from snow, backfilling trenches and pits, erecting an embankment in a longitudinally circular pattern, and others where a blade with variable geometry can be used as a track-laying or rotary dump. The analysis of the workflow and the development of methods for calculating the parameters of such an adapted design is of great interest and is essential for the creation of alternative universal bulldozer equipment.

The calculation scheme (Fig. 2) for the analysis of the force interaction of an adaptive-type variable-geometry dump with the environment is built according to the main provisions of the analytical method described in [19], in accordance with which the main assumptions were made: the soil can be present in the form of a mass with the properties of a granular medium - with adhesion during cutting and movement along the surface of the blade and without adhesion after tipping over; the angle of soil friction along the blade is less than the angle of internal friction; sliding surfaces have a shape corresponding to the direction of movement with the least resistance; soil layers moving along the dump sections are incompressible; the speeds of the particles that make them up are the same; inertial forces can be neglected.

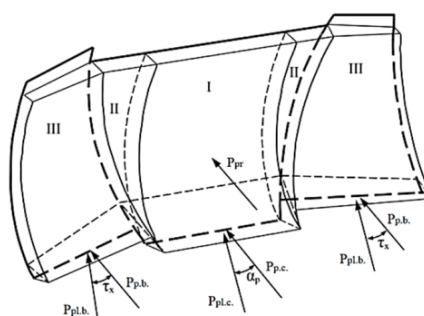


Fig. 2. Scheme of the main components action of digging resistance on a retractable blade of a bulldozer with variable geometry.

In order to simplify the analysis, it is assumed that there are no blunt areas on the cutting knives. The determination of the digging resistance components is based on the principle of superposition, all resistances are calculated separately for the middle and side sections, as was done in the study of spherical dumps [4]. When compiling the design scheme and determining various resistances, the features of the dump with variable geometry, identified in the analysis of geometric dependencies between its parameters and experimental studies, were taken into account. The stress state of the soil in front of each section is conditionally considered as flat, and the spatiality of the processes is taken into account by introducing additional forces of interaction between adjacent soil layers.

The horizontal component of the digging resistance, in accordance with the diagram in Fig. 2 is determined by the expression

$$P_{01} = P_{p.c} + P_{pl.c} \cdot \cos \alpha_p + 2P_{p.b} + 2P_{pl.b} \cdot \cos \tau_x + P_{pr}, N \quad (1)$$

where $P_{p.c}$ - cutting resistance, taking into account the load from the soil layers moving from the dump; P_{pr} - resistance of the prism to drawing.

The cutting resistance of the middle section is determined by the well-known formula [20]:

$$P_{p.c} = \left(1 + \operatorname{ctg} \alpha_p \cdot \operatorname{tg} \delta\right) \cdot A_1 \cdot b_c \cdot h_c \left[\frac{Y \cdot h_c}{2} + C_0 \cdot \operatorname{ctg} \rho \left(1 - \frac{1}{A_1}\right) + P_{pl.c}\right] \quad (2)$$

where δ – the angle of soil friction on metal, deg.; A_1 – non-dimensional coefficient determined for the case $\alpha_p > \arcsin \frac{\sin \delta}{\sin \rho} - \frac{\delta}{2}$:

$$A_1 = \frac{\cos \delta \cdot (\cos \delta + \sqrt{\sin^2 \rho - \sin^2 \delta})}{1 - \sin \rho} \cdot e^{(2\alpha_p - \pi + \delta + \arcsin \frac{\sin \delta}{\sin \rho}) \cdot \operatorname{tg} \rho} \quad (3)$$

$p_{pl.c}$ – average pressure on the chip being cut out from the soil moving along the middle section of the formation, determined by the expression

$$p_{pl.c} = \frac{P_{pl.c} \cdot \sin \alpha_p}{b_c \cdot a_c}, \text{ Pa}, \quad (4)$$

where $a_c = \frac{\operatorname{tg} \alpha_p + \operatorname{tg} \psi}{\operatorname{tg} \alpha_p \cdot \operatorname{tg} \psi} \cdot h_c$ - average shaving thickness; $\psi \approx \frac{\pi}{4} - \frac{\rho}{2}$ - average value of the shift angle;

$h_c = \frac{B_0 \cdot h_{e,k} + (Y_B - Y_A) \cdot (Z_B + Z_A)}{b + 2(Y_B - Y_A)}$ - cutting depth with an average knife, m; C_0 - adhesion of soil with undisturbed structure, Pa.

The determination of the horizontal component of cutting resistance by the side section is associated with a number of features of an adaptable blade with variable geometry. When installing the side section at an acute angle of capture, the separation of the soil from the array is accompanied by its movement in the transverse direction. As the calculated value of the angle of inclination of the trajectory to the line of intersection of the knife with the horizontal plane, you can take a value equal to the angle of capture [20]. At the same time, it is assumed that the deformations from the intersection of the trajectories of the middle and side chips along the length of the side knife are insignificant. Thus, the direction of the trajectory t of the soil movement along the lateral section is determined by the polar angles τ_x, τ_y, τ_z , calculated from dependences (5).

$$\cos \tau_x = \frac{-\cos^2 v_x \cdot \cos v_z + \cos^2 v_y}{\sin^2 v_z} - 1, \cos \tau_y = \frac{\cos v_x \cdot \cos v_y \cdot (1 - \cos v_z)}{\sin^2 v_z} \quad (5)$$

The skew of the side section relative to the horizontal plane changes the shape of the chips separated from the array. Depending on the depth of cut, it can be triangular or trapezoidal.

The integration area D depending on the depth of cut h corresponds to the triangle AN'M' or the quadrilateral ABNM (Fig. 3). In order to simplify the calculated dependencies, it is accepted $Y_{M'} = Y_M = Y_A$ and $Y_N = Y_B$, while the maximum error in determining $P_{p.c}$ in the possible range of changes in the cutting depth and geometrical parameters of the section does not exceed 4%.

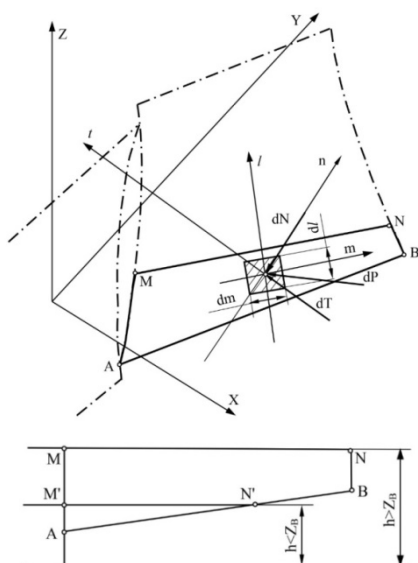


Fig. 3. Scheme for calculating the cutting resistance of the side section of a retractable blade with variable geometry.

The total value of the horizontal component of the cutting resistance with a side knife after the transformations has the form

$$P_{p,\delta} = \left(1 + tg\delta \cdot \frac{\cos \tau_x}{\cos \nu_x}\right) \cdot A_1 \cdot ctg\delta_{otk} \cdot h_z \cdot \left\{ \frac{\gamma}{2} \left(h^2 - \frac{h_z^2}{3} \right) + \left[C_0 \cdot ctg\rho \left(1 - \frac{1}{A_1} \right) + p_{pl.b.} \right] \left(h - \frac{h_z}{2} \right) \right\}, N \quad (6)$$

τ_x - one of the polar angles ($\tau_x; \tau_y; \tau_z$) of the straight line t , tangent to the trajectory of the particles of the medium along the blade of the side section of the blade with variable geometry, deg.;

δ_{otk} - the angle of the formed slope or the angle between the projection of the cutting edge of the side section on the vertical plane perpendicular to the longitudinal axis of the bulldozer and the horizontal plane, deg.

To establish the values of $P_{pl.c}$ and $P_{pl.b}$ in expressions (2) and (4), it is necessary to determine the forces of resistance to the rise of the layers by the average $P_{pl.c}$ and the lateral section $P_{pl.b}$.

On the calculation scheme in Fig. 2, the dump surface with the soil layer located on it is divided into separate sections with characteristic trajectories of soil particles movement and a load action scheme for each.

The most loaded is the soil layer, cut out with a middle knife and rising along the central section I of the middle section. The loads acting on the formation are shown in Fig. 4. Since it is impossible to obtain stress and strain functions that satisfy the conditions of equilibrium, continuity, and uniqueness in a closed form, the calculation of the actual trajectories of soil particles causes significant difficulties. To simplify the following reasoning, it is assumed that the particle trajectories and the boundaries of the central section I are parallel to the vertical XOZ plane. The soil enters section II of the middle section from the side oblique sections. In the absence of other influences, the trajectories of particles of soil flows descending from the side knives would remain in the planes passing through the trajectories of movement, as is the case with straight oblique blades, along with the cutting knives (lines t in Fig. 2). The mass repulse forces - $P_{pl.b}$, which promote side flows, in this case, are directed opposite to the speeds of movement. The interaction of the central layer cut out by the VSN with the side layers crossing the direction of its movement leads to the deformation of the latter and the alignment of the velocities of their particles in direction and magnitude as they approach section I. The direction of the repulse forces $P_{pl.b}$ does not change, since the resultant forces of deformation and resistance to lifting.

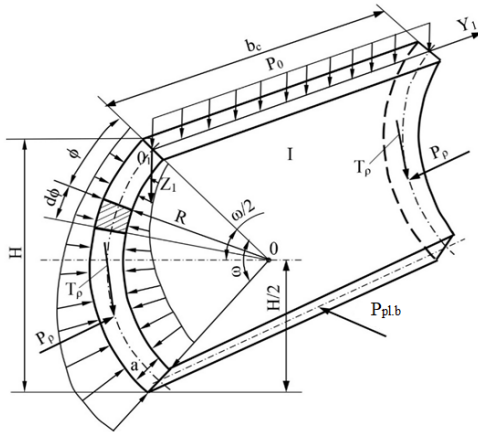


Fig. 4. Calculation scheme for determining the resistance to the formation rise in section 1 of the middle section of the dump with variable geometry.

To simplify the calculation scheme, it is accepted the assumption that the trajectories of particles in section I, and the speed of their vertical advance are less. Thus, at the boundaries of sections I and II, friction forces arise that are proportional to the force of the side layers deformation. With their increase, the resistance to the rise of the middle layer increases, and at values above the limit, the section surface is no longer a sliding surface.

To determine the unknown forces $P_{pl.c}$ and $P_{pl.b}$ in accordance with the principle of superposition, it is established the resistance to the lifting of the soil in each of the selected sections, with the corresponding forces.

Section I (Fig. 4):

The rise resistance of the central layer is determined by $P_{pl.c} = T_1 + 2T\rho$, N,

where T_1 - the resistance of the soil to the rise along the central section I, due to the formation friction on the dump and the drag prism, the bending of the formation, its own weight, and surcharge from above:

$T\rho = tg\rho \cdot P\rho$ - the friction force between the soil layers at the boundaries of sections I and II.

Here $P\rho$ is the resultant pressure at the end face of the central layer.

To determine T_1 , the formula obtained in [19] is used:

$$T_1 = (tg\delta + tg\rho) \cdot \gamma\rho \cdot \cos^2\rho \cdot b_c \cdot H^2 \cdot k \cdot \arcsin \frac{1}{2k} \left(1 + tg\delta \arcsin \frac{1}{2k} \right) + \gamma\rho \cdot b_c \cdot a_c \cdot H_{pr}, N(7)$$

where T_1 – resistance force of the soil to rise along with the central section, due to the friction of the formation on the dump and the drag prism, the bending of the formation, its own weight and surcharge from above; b_c – middle knife width, m; $k = \frac{R}{H}$ - coefficient; $\gamma\rho$ – the volumetric weight of the soil constituting the formation; ρ and δ - angles of internal friction of the cut soil layer, respectively, along with the drawing prism and the blade surface, deg. Their tangents are friction coefficients, dimensionless quantities.

Section II (Fig. 5).

Neglecting the friction force at the boundary of sections I and II, directed along the movement in section II, the resistance T_2 to the rise of the triangular formation is determined as the resistance from friction along the dump surface, bending, and surcharge from above. To do this, the dependence [20] is applied, which expresses the lifting resistance as a function of the current polar coordinate ϕ :

$$T = \left(\frac{A \cdot R \cdot H}{2 \cdot tg\delta} - \frac{A \cdot R^2}{1 + tg^2\delta} \cdot tg\delta \cdot \sin \frac{\omega}{2} + \frac{A \cdot R^2}{1 + tg^2\delta} \cdot \cos \frac{\omega}{2} + P_0 \right) e^{tg\delta \cdot \phi} - \left[\frac{A \cdot R \cdot H}{2 \cdot tg\delta} + \frac{A \cdot R^2}{1 + tg^2\delta} \cdot tg\delta \cdot \sin \left(\phi - \frac{\omega}{2} \right) + \frac{A \cdot R^2}{1 + tg^2\delta} \cdot \cos \left(\phi - \frac{\omega}{2} \right) \right], N \quad (8)$$

where

$A = (tg\delta + tg\rho) \cdot \gamma\rho \cdot \cos^2\rho \cdot B_{pl} = D \cdot B_{pl}$ – coefficient; $D = (tg\delta + tg\rho) \cdot \gamma\rho \cdot \cos^2\rho$ – coefficient; B_{pl} – layer width.

Here, the polar angle ϕ and the current coordinate Z_1 are related by the dependence

$$Z_1 = \frac{H}{2} + R \cdot \sin \left(\phi - \frac{\omega}{2} \right) \quad (9)$$

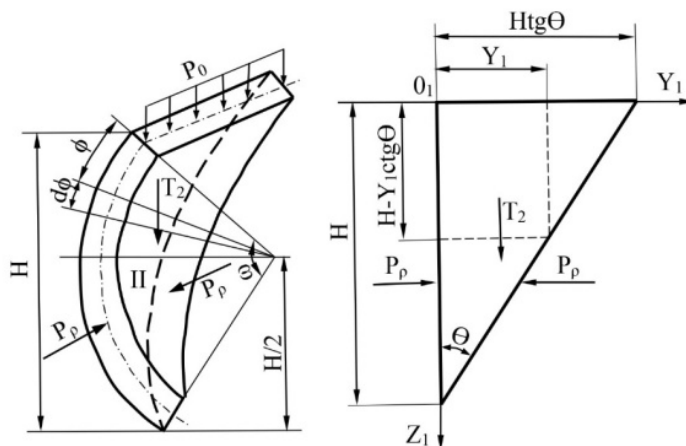


Fig. 5. Calculation scheme for determining the resistance to the rise of the formation in section 11 of the middle section of the dump with variable geometry.

From the analysis of formula (9) it follows that with a constant over the width of the formation top-loading $\rho_0 = P_0/B_{pl}$, the resistance to the rise of the formation along the dump surface is directly proportional to its width and the intensity of resistance along the width can be expressed

$$q(\vartheta) = \frac{T(\vartheta)}{B_{pl}}, \text{ N/m} \quad (10)$$

or

$$q(\vartheta) = \left(\frac{D \cdot R \cdot H}{2tg\delta} - \frac{D \cdot R^2}{1+tg^2\delta} \cdot tg\delta \cdot \sin \frac{\omega}{2} + \frac{D \cdot R^2}{1+tg^2\delta} \cdot \cos \frac{\omega}{2} + P_0 \right) \cdot e^{tg\delta \cdot \vartheta} - \left[\frac{D \cdot R \cdot H}{2tg\delta} + \frac{D \cdot R^2}{1+tg^2\delta} \cdot tg\delta \cdot \sin \left(\vartheta - \frac{\omega}{2} \right) + \frac{D \cdot R^2}{1+tg^2\delta} \cdot \cos \left(\vartheta - \frac{\omega}{2} \right) \right], \text{ N/m} \quad (11)$$

For the total resistance to the rise of the reservoir in section II, after solving the integrals and some transformations, the following dependence is obtained

$$T_2 = tg\theta \cdot R \cdot \left\{ \left[\frac{D \cdot R \cdot H}{2tg\delta} - \frac{D \cdot R^2 \cdot (tg\delta \cdot \sin \frac{\omega}{2} - \cos \frac{\omega}{2})}{1+tg^2\delta} + \rho_0 \right] \cdot \left[\frac{(e^{tg\delta \cdot \omega} - 1) \cdot tg\delta \cdot \cos \frac{\omega}{2} + (e^{tg\delta \cdot \omega} + 1) \sin \frac{\omega}{2}}{1+tg^2\delta} \right] - \frac{D \cdot R \cdot H}{2tg\delta} \sin \frac{\omega}{2} \right\} \quad (12)$$

Plot III (side section):

The scheme of loading the soil layer in the area is shown in fig. 6, 7.

The backlash force of the massif $P_{pl.b}$ is determined by the force T_2 and the resistance to the advance of the formation along with the lateral section T_3 . It is necessary to decompose the latter into components: T_3' - in the direction ρ , perpendicular to the generatrix of the cylindrical surface, T_3'' - in the direction of the generatrix q .

From the condition of the forces balance along the vertical axis $\sum Z_1 = 0$,

$$P_{pl.b} = \frac{1}{\cos \tau_z} \cdot (T_3' \cdot \cos \pi_z + T_3'' \cdot \cos \xi_z + T_2), \text{ N} \quad (13)$$

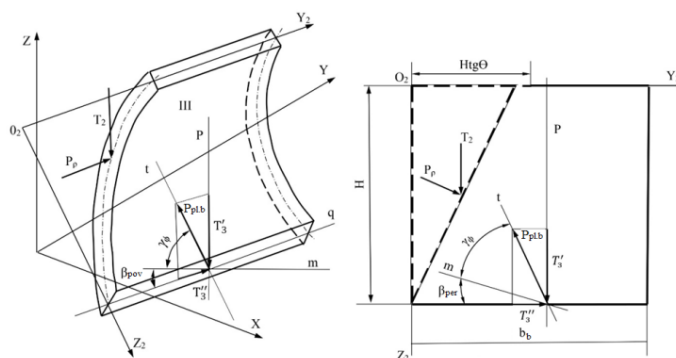


Fig. 6. Calculation scheme for determining the resistance to the rise of the formation along the surface of the side section of the dump with variable geometry.



Fig. 7. Digging the soil with a blade with variable geometry with an angle of $\theta=30^\circ$.

The resistance T_3 to the rise of the formation along the lateral section is determined, considering section III as a straight dump with a width b_b and a height H . It is necessary to take into account the missing triangular section of the surface by subtracting the fictitious force T_3^0 , which is determined using the expression obtained above.

$$T_3' = (tg\delta + tg\rho) \cdot \gamma_p \cdot \cos^2\rho \cdot b \cdot H^2 \cdot k \cdot \arcsin \frac{1}{2k} \left(1 + tg\delta \cdot \arcsin \frac{1}{2k} \right) + \gamma_p \cdot b_\delta \cdot a_\delta \cdot H_{pr} - T_3^0 \quad (14)$$

where

$$a_b = \frac{tg\alpha_p + tg\rho}{tg\alpha_p \cdot tg\psi} \cdot h_{sr.b}; \quad b_b = \frac{B-b}{2} \quad (15)$$

Here $h_{sr.b}$ – average digging depth by the side section.

Based on the relatively lower sensitivity of the optimal value of the slip coefficient to soil conditions, for such limited purposes as comparing the maximum performance of bulldozers in various soil conditions, it is possible to take the optimal value of the slip coefficient constant on all soils and, on this basis, determine the remaining parameters of the optimal traction-speed mode. The optimal value of the specific traction force can be determined from the above dependence, in which the optimal value of the slip coefficient is substituted, and the argument is the maximum coefficient of adhesion on a given soil:

$$\psi_{opt} = [1 - (1 - \delta_{opt})^{6,67}] (\varphi_{sc} - f - 0,07) + f \quad (16)$$

The formula for determining the technical performance of a bulldozer with an optimal traction-speed mode in arbitrary soil conditions is reduced to the form [18-19]:

$$P_T = \frac{3,6 \cdot \eta \cdot Ne}{K_t \cdot K_\rho \cdot (K_1 \cdot K_k + K_2 \cdot \frac{G \cdot L}{q})}, \text{ m}^3/\text{h} \quad (17)$$

where coefficients

$$K_1 = \frac{1}{K_3 \cdot K_{pk} \cdot K_p \cdot (1 - \delta_{opt}) \cdot (1 - f / \psi_{opt})} \quad (18)$$

$$K_2 = \frac{\psi_{opt}}{K_3 \cdot (1 - \delta_{opt})} + \frac{f}{K_{3x}} \quad (19)$$

With an increase in the strength of the soil, the process of its deformation during the deepening of the dump slows down. To avoid hanging the bulldozer on the blade and slipping in place, the average blade lowering speed is controlled by periodically turning off the drive hydraulic cylinders. Since an increase in the length of the path l_3 , on which the deepening occurs (Fig. 8), leads to an extension of the idling of the bulldozer, with a decrease in the average speed of lowering the blade, the speed of the bulldozer should also be reduced so that in the ranges of possible regulation of the speeds V_3 and V , ratio

$$\frac{V_3}{V} = tg\beta_h \approx \text{const} \quad (20)$$

where

$$\beta_h = \arctg \frac{H}{l_3} < \beta_3 \quad (21)$$

V_3 - the speed of dump deepening, km/h;

V - the speed of the bulldozer in the process of deepening the dump, km/h;

β_h – vertical angle of dump penetration (Fig. 8), deg;

β_3 – back angle of the blade, deg.

The vertical component of the resistance to blade penetration into the ground can be determined (with satisfactory convergence with the experimental results [11]) as the resistance to indentation of the knife on its blunt area without taking into account the influence of the normal friction force on the front area. The calculation formula has the form [20]:

$$R_2 = [\sigma] \cdot S \cdot B + K_2 \cdot B, N \quad (22)$$

where B – blade cutting edge length, m; S - the width of the blunting area, for new knives $S = 0.01 \dots 0.015$ m [16]; $[\sigma]$ – ultimate bearing capacity of the soil, MPa; K_2 - the specific soil reaction per unit length of the cutting edge, MN/m.

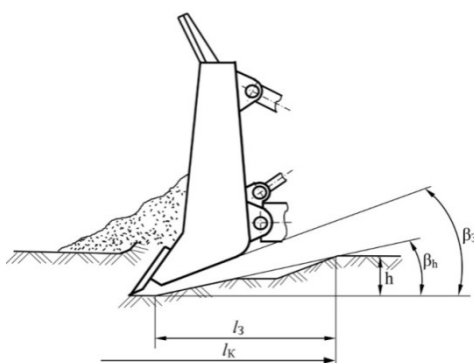


Fig. 8. Scheme of deepening the bulldozer blade into the ground.

The minimum possible time for the operation of deepening the dump is expressed by the dependence

$$t_{3min} = \frac{h \cdot \xi^2}{\text{tg } \beta_h \cdot \left(\frac{K_G \cdot G}{B \cdot [\rho]} - 1 \right)^2}, \text{ s.} \quad (23)$$

Here, the K_G coefficient has the meaning of the ratio of the maximum linear vertical load on the soil under the cutting edge of the blade to the ultimate linear bearing capacity of the soil.

The obtained dependence makes it possible to evaluate the effect on the time of dump penetration (with full use of the deepening force of the bulldozer and the rational value of the ratio $\frac{h}{l_3} = \text{tg } \beta_h$), the effect of the bulldozer weight, its layout, and the design of the working equipment (through the coefficient of weight transfer to the cutting edge of the blade $K_G = 0.3 - 0.45$), length cutting edge and ultimate bearing capacity of the soil $[\rho]$.

On fig. 9 shows the relative change in the time of deepening $t_{3,0}$ of the blade with the reference length of the edge V_e . The curves are plotted for soils with different bearing capacities, expressed as fractions of the maximum linear load on the soil under the cutting edge of the reference blade with constant values of the other parameters (h - the height of the cut soil; G - the weight of the bulldozer). Comparison, for example, of the penetration time of a direct blade, adopted by the standard, and a spherical one, the length of the cutting edge of which is 10% longer ($V/V_e = 1.1$) on soils with a different bearing capacity $[\rho]$ shows: with $[\rho] = 0,8 \frac{K_G \cdot G}{V_e}$ the spherical blade penetrates 2.5 times slower, and on soil with $[\rho] = 0,9 \frac{K_G \cdot G}{V_e}$, no penetration occurs at all.

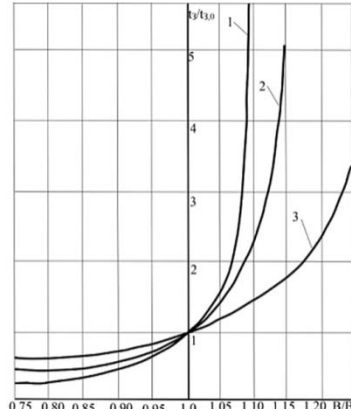


Fig. 9. Influence of the cutting edge length on the time of deepening the dump into soils of various strengths:

$$1 - [p]=0,9[p]_0; 2 - [p]=0,8[p]_0; 3 - [p]=0,7[p]_0; [p]_0 = \frac{k_g \cdot G}{B_e}.$$

The calculated technical performance curves for a bulldozer with a straight and spherical blade on medium loam, with and without taking into account the time for the deepening operation, is shown in Fig. 10. Comparison of the data on the experimental determination of the full-scale bulldozer productivity with a straight and spherical blade, performed in the indicated soil conditions at $l = 30$ m, with the calculated data shows that the discrepancy, if the penetration time is not taken into account, is for a straight and spherical blade, respectively, 9.6% and 29 %, and in the case of accounting, the discrepancy is for both dumps within 6-7%.

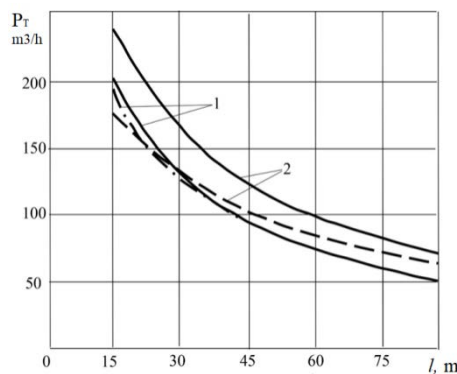


Fig. 10. Change in the technical performance of a bulldozer on soil II - III categories with dumps: 1, 2 - respectively, straight and spherical; Solid lines - without taking into account the time of dump penetration; dashed lines - taking into account; \circ and \bullet are the obtained experimental values, respectively, for a straight and spherical blade/

2 CONCLUSION

1. Theoretical dependences obtained on the basis of the provisions of the granular medium statics with adhesion make it possible to analytically estimate the dimensions and volume of the drag prism and the horizontal component of the resistance to digging by an adaptive-type blade, in particular, by spherical-type blades (spherical and hemispherical). Using the developed dependences, the influence of the physical and mechanical properties of the soil, geometric parameters (length and height of the blade, length of the middle section, cutting angles, installation of hinges in the longitudinal and transverse planes, and installation angles of the side sections), as well as the digging depth on the digging process can be investigated. Dependencies can be used in determining the productivity and traction calculation of bulldozers with adaptive and spherical blades (at $\Theta = 0^0$) of the type.

2. Refined dependencies for determining the productivity of bulldozers make it possible to calculate the highest productivity achievable with the optimal traction-speed mode of the bulldozer in specific soil conditions, taking into account the time for the blade deepening operation. They allow a more reasonable approach to comparing the efficiency of bulldozers with different accumulative capacities and concentration of working efforts on the working body.

3. To verify the correctness of the assumptions made, and the reliability of the developed analytical dependences for substantiating the rational design parameters of an adaptable dump with variable geometry, it is necessary to conduct experimental studies of the soil digging process.

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