

*The presented results of scientific research are aimed at increasing the efficiency of trenching for laying the utility lines using new less energy-consuming technologies of excavating the soil with the working equipment of multi-scrapers excavators.*

*The proposed method of determining the efficient operating modes for excavators when digging a trench is based on the idea of cutting the soil with the blades at a critical depth level, which guarantees consumption of minimum specific energy and maximum efficiency of the machine. This becomes possible if the operation of such blades is provided with the absolute values and the ratio of the speeds of cutting and submitting the working body into the face.*

*To determine the efficient modes of multi-scrapers excavators and the size of their edge side blades, the conditions of their effective unloading were identified and the patterns of changing the soil movement over the surface of unloading scrapers depending on the time of unloading were determined. For the same purpose, the dependences of the blocked cutting speed on the trench width were determined and the technical performance of the excavator was specified on the basis of determining the soil bearing capacity for one group of blades. It is found that the time of unloading the soil from the scrapers very slightly depends on their angular velocity within its change in the unloading zone. On this basis, the maximum angular speed of the scrapers is determined. The identified indicators are related to the width of the edge side blades performing asymmetric locked cutting, whose dimensions were determined by calculations.*

*The obtained efficient operating modes of scraper trench excavators and the size of their edge side blades allow developing practical recommendations for improving the working equipment of excavators of this type*

*Keywords: trench digging, trench excavator, scraper excavator, scraper, blade, critical depth, soil cutting*

# DETERMINING EFFICIENT OPERATING MODES AND SIZES OF BLADES FOR MULTI-SCRAPER TRENCH EXCAVATORS

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## 1. Introduction

The works on laying the linear part of pipelines can be performed both by their laying in open trenches [1] and with the use of trenchless technologies of their laying in the ground [2–4]. With all the advantages of the latter, the traditional trench technologies remain preferable in the construction of long sections of distribution utility lines. Earthworks are performed in all countries of the world by specialized companies using both general construction machines and special scraper and rotary trench excavators. Pipeline construction in Ukraine is performed by such specialized enterprises as PJSC Ukrtransgaz and Ukrtransnafta, in Russia – by RAO Gazprom and JSC Transneft and their

contractors [1], in the USA – by Shell and Esso Pipeline, Chevron Pipeline, Natural Gas Pipeline Company of America [5–7], in Saudi Arabia – by Saudi Arabian Oil Company and Trans-Arabian Pipeline Company [8, 9].

In Ukraine, Russia and other countries, a number of continuous earthmoving machines of sufficient technical level have been manufactured. These are PZM-3, ETC-200 machines in Ukraine, TMK-3, ETR-254A, ETC-252 in Russia, Vermeer T955 Commander III and Vermeer 1055 Commander III [10], Trenchor 1460 HD and Trenchor 1080 HD [11], Cleveland B-92 and Cleveland IC-36 [12] and others. These excavators can build long hollows of a given profile in the open field (for which they are intended). The rate and cost of engineering utilities depend on their performance and efficient use.

Therefore, improving working equipment of the scraper type trench excavators, which is aimed at increasing its efficiency, is an urgent task.

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## 2. Literature review and problem statement

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In [13], an analytical dependence for estimating the effect of primary humidity of soil on the duration of excavator bucket unloading is obtained in the form of a polynomial of the second degree, but the impact of the form, quantity and placement of blades on the excavator performance is not considered.

In [14], an approach is proposed based on determining the forces acting on the bucket of a hydraulic excavator during soil excavation providing a real-time force assessment, which is a necessary prerequisite for addressing the development of unmanned earthmoving machines. The issue of improving the efficiency of trench excavators was not considered.

The research in [15] is devoted to determining the values and patterns of distribution of operating loads acting on the bucket excavator and can cause the loss in the machine stability. The boundary conditions of stability loss are obtained by means of numerical modeling and experimental tests. The loss of stability of multi-bucket excavators and the impact of the scraper working body blades on it was not considered.

In [16], the methodology for creating a light and high-strength design of an excavator bucket under indefinite load is presented, obtained by Monte Carlo modeling based on the existing model of soil interaction with the bucket. Modeling of the excavator bucket using the ANSYS program allowed determining the directions of diminishing the maximum stress according to Mises and reducing the weight of the bucket. The impact of the working equipment parameters and the soil environment was not specified.

In [17], based on scientific research of trenching by multi-scraper excavators of continuous action, the basics of designing excavators of continuous action are laid, rational constructive and kinematic parameters of the chain-beam working body of earthmoving machines are determined. The issue of reducing energy consumption during these works by diminishing energy expenditure when cutting the soil with excavator blades is not considered. The calculated dependences of soil cutting processes and speed-time-distance calculations proposed in [18] also do not give a clear answer to this question. The search for rational modes of trench chain excavator's operation due to innovative continuous earthmoving machines is shown in [19]. Substantiation and selection of the main parameters of the chain excavators cutting tool are given in [20]. But in [19] and [20], the possibility of reducing the energy consumption of the soil cutting process in the mode of critical depths is not taken into account.

From the review, we can conclude that at present there are two methods for determining the parameters and modes of operation for multi-scraper chain trenchers. One of them proposes to determine the design parameters of the working body through the specified engine power of the base machine and the parameters of the trench [17, 18]. Another one allows determining the required engine power of the base machine based on technical performance, specific resistance to soil digging and the size of the trench [19, 20].

The known techniques do not guarantee the implementation of the working process at a critical cutting depth with the consumption of minimum specific energy and maximum performance. This will be possible if all the blades, regardless

of their location, type of cutting and soil conditions, will break the soil to a critical cutting depth, which is provided by the absolute values and the ratio of cutting speeds and submission of the working body into the face. This effect is considered in [20] for deep cutting of soils by blade work tools.

Thus, it can be affirmed that conducting the research aimed at determining effective operating modes for scraper excavators and the size of their blades operating in the mode of critical depth of soil cutting is appropriate.

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## 3. The aim and objectives of the study

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The aim of the study is to determine the least energy-intensive operating modes for multi-scraper excavators based on specification of critical depths of soil cutting by the blades that perform blocked (symmetric and asymmetric) soil breakage.

The objectives of the research are:

- to determine efficient operating modes of multi-scraper trench excavators in which the blades work in the conditions of blocked soil cutting;
- to specify the technical performance of the excavator and to set the widths of the edge side blades that perform asymmetric blocked soil cutting.

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## 4. Materials and methods of the research

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It was found out [19] that the energy consumption, dynamic loads on the chains and the performance of the excavator depend on the shape of the blades, their number and arrangement. Multi-scraper chains excavate and transport the soil in the following ways:

- 1) distributive – the blades pre-break the soil across the width of the trench, and subsequent scrapers transport the broken soil to the day surface;
- 2) integrated – scrapers-blades simultaneously break and transport the soil to the place of unloading;
- 3) combined – this is performed in the same way as a distributive method, the only difference being that the blades not only break the soil but also partially transport it.

According to the works [17, 18], the integrated scheme of soil excavation and transportation is the most universal and optimal.

Blades are the most versatile and effective for soil destruction, and flat scrapers – for soil transportation. Integrating them into one unit – a scraper-blade, in which the basis for fixing the blades is a flat scraper (beam) – is logical, because such blades have a minimum area of contact with the soil in the process of its breaking.

Criteria for rational placement of blades [18] – energy consumption of cutting, for which it is necessary to ensure work with a large chip, minimum dynamics of loads on the working body, versatility of the scheme, maximum performance or speed of the machine – are not taken into account when choosing the schemes of placing the blades. The choice of the scheme for blades arrangement and their number depend, as a rule, on the width of a trench and the form of blades, but not on soil conditions and the criteria of rationality of blades placement. It is the main disadvantage of existing methods for choosing and calculating the parameters of multi-scraper chain trench excavators.

As a result of research [19], it is known that when the blades start cutting the soil at a critical depth, this reduces

the energy consumption of the working process because the intensity of the resistance to cutting is less than the cross-sectional area of the cut. The intensity of resistance to cutting increases as the soil is pressed into the side walls of the cut, and the area of breakage decreases as it is impossible to influence the process of breaking the soil of the day surface. As a result, the energy consumption of the workflow increases.

It is ascertained that the known analytical-experimental models of interaction of multi-scraper chain trench excavators with the soil do not determine the parameters and modes of their operation based on the idea of the critical depth of soil cutting. From this, we can conclude that they do not provide minimum energy consumption and maximum performance of the workflow.

In [20], the idea of cutting soils with blades of chain-scraper excavators at critical depth was proposed, but the results of these studies were not implemented for specific soil types due to their physical and mechanical properties and geometric parameters of the blades. This requires appropriate mathematical models that would take into account the conditions of soil cutting with excavator blades at the critical depth and the length of the blade.

The conducted scientific theoretical and experimental research [18–20] with the participation of the authors were the basis for the proposed following research aimed at developing a methodology for determining effective operating modes of multi-scraper trench excavators according to the trench width during their designing and operation.

### 5. Determining efficient operating modes of multi-scraper trench excavators

The main technological parameters of scraper excavators, which determine their efficiency, include the speed of soil cutting and the time of unloading its scrapers.

The cutting speed  $v_c$  depends on the angular velocity and the radius of the drive sprocket. The angular velocity  $\omega$  is substantiated on the basis of determining the unloading time  $t_{un}$  and the unloading angle  $\varphi_{un}$  depending on the coefficients of edge friction of the soil  $\mu_1$  and the height of the scraper  $h_s$ , provided that  $\varphi_{un} = \omega t_{un} = \pi/2$  (Fig. 1).

The unloading condition is corrected by the angular velocity  $\omega$ . Due to the fact that the soil unloading time significantly depends on the height of the scraper and negligibly depends on the angular velocity within its change  $\omega = 5.0 \dots 9.0 \text{ s}^{-1}$  (Fig. 1), the maximum angular velocity can be determined as  $\omega_{max} = \pi/2t_{un}$ . Then the cutting speed will be equal to (m/s):

$$v_c = \frac{t_{chain}}{2 \sin \frac{180^\circ}{n_z}} \omega_{max} \quad (1)$$

where  $t_{chain}$  is the pitch of connecting the chain links ( $t_{chain} = 0.1 \dots 0.2 \text{ m}$ );  $n$  is the number of teeth of the drive sprocket ( $n_z = 7 \dots 11$ ).

Data analysis in Fig. 1 shows that the unloading time practically does not depend on the angular velocity within its change  $\omega = 5.0 \dots 9.0 \text{ s}^{-1}$ . On this basis, the paper determines the maximum angular velocity ( $\omega_{max} = \pi/2t_{un}$ ) and the relative speed of soil cutting with blades  $v_c$ .

Dependences in Fig. 2 are obtained by calculation according to formula (1), respectively for different maximum

angular velocities, which are determined from the condition of unloading the soil on the scrapers at the time of their rotation in the unloading zone at the angle  $(\pi/2)$ . It is taken into account that the height of the scraper depends on the width of the trench  $B$  [19].

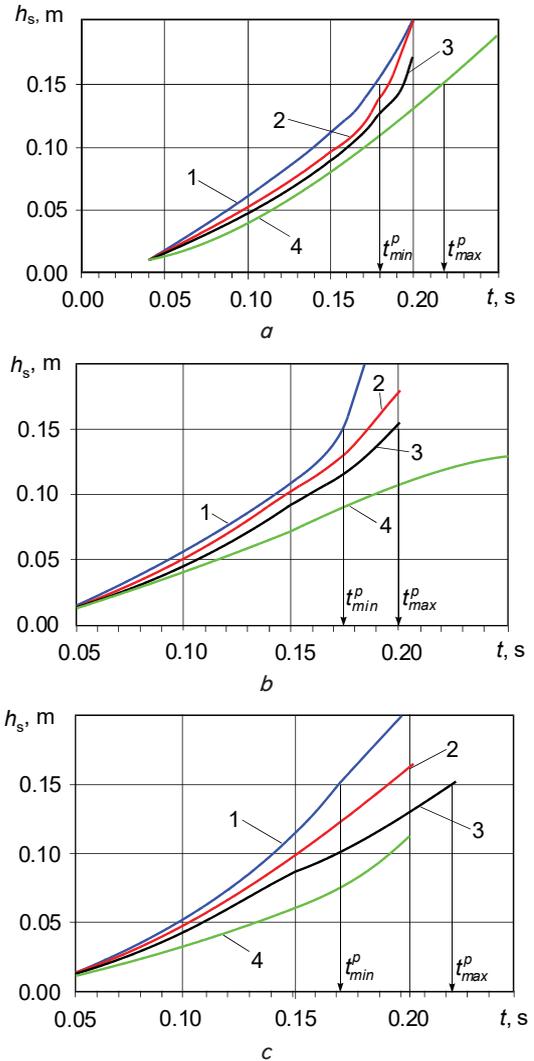


Fig. 1. Dependences of the change of soil movement over the surface of unloading scrapers on the time of unloading:  $a - \omega = 5.0 \text{ s}^{-1}$ ;  $b - \omega = 7.0 \text{ s}^{-1}$ ;  $c - \omega = 9.0 \text{ s}^{-1}$ ; 1 -  $\mu_1 = 0.2$ ; 2 -  $\mu_1 = 0.3$ ; 3 -  $\mu_1 = 0.4$ ; 4 -  $\mu_1 = 0.6$

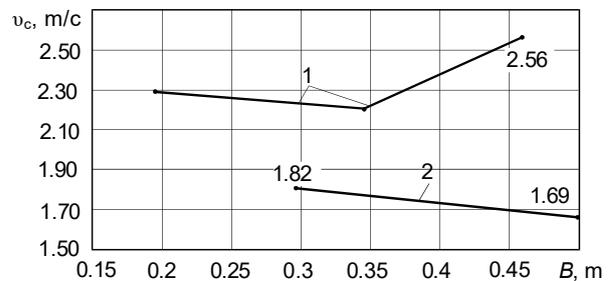


Fig. 2. Dependence of the speed of blocked cutting of semi-solid loam on the trench width: 1 - for the width of the blades  $b_{bl} = 0.02 \text{ m}$  with the cutting angle  $\alpha_c = 30^\circ$ ; 2 - for the width of the blades  $b_{bl} = 0.03 \text{ m}$  with the cutting angle  $\alpha_c = 30^\circ$

From the obtained diagram (Fig. 2), it can be seen that the cutting speed  $\vartheta_c$  by the blades working at a critical depth is directly related to their width. Increasing the width of the blade from 0.02 m to 0.03 m when digging a trench in the loam requires 1.5 times reduction in cutting speed.

**6. Determining the technical performance of the excavator and the width of the edge side blades**

Technical performance ( $m^3/h$ ) of the excavator is determined by bearing capacity of soil for one group of the blades which are in the face ( $z_s^z = 1$ ):

$$\Pi_{techn}^1 = 3,600 \cdot B h_s \vartheta_c \frac{k_f}{k_c} \Delta_c, \tag{2}$$

where  $B$  is the width of the trench, m;  $h_s$  is the height of the scrapers, it is determined according to the method [22], m;  $k_f$  is the coefficient of filling the inter-scraper excavation space (for soils of I...IV categories, respectively 0.9...1.2 and 0.7...0.9) [1, 14];  $\Delta_c$  is the shaking coefficient ( $\Delta_c = 0.97; 0.92; 0.85; 0.75$ , respectively for  $\vartheta_c = 0.1; 1.0; 1.5; 2.0$  m/s) [7].

If there are a number of blades in the face equal to  $z_{gr}^z$ , then the technical performance will be determined by the dependence:

$$\Pi_{techn} = \Pi_{techn}^1 \cdot z_{gr}^z. \tag{3}$$

Technical performance depends in direct proportion on the number of groups of blades in the face, so:

$$\Pi_{techn} = \Pi_{techn}^1 \cdot z_s^z. \tag{4}$$

The width of the trench  $B$  (5) for the scheme of blades with blocked cutting is determined according to the scheme of their arrangement (Fig. 3) on the condition that the edge side blades with the width of  $b'_{bl}$  interact with the vertical walls of the trench.

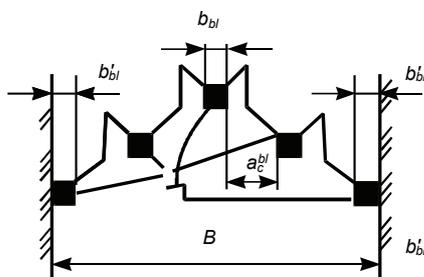


Fig. 3. Scheme of blades arrangement and their sizes

From the given Fig. 3, the width of the trench for the scheme of blades with blocked cutting is equal to:

$$B = 2b'_{bl} + (i_t^{bl} - 2)b_{bl} + (i_t^{bl} - 1)a_c^{bl}, \tag{5}$$

where  $b'_{bl}$  is the width of the edge side blades;  $b_{bl}$  is the width of the middle blades carrying out the blocked cutting;  $a_c^{bl}$  is the distance between the side edges of two adjacent blades;  $i_t^{bl}$  is the integer number of blocked cutting lines, it is determined, for example, for semi-solid loam and the blade width  $b_{bl} = 0.02$  m with different cutting angles  $\alpha_c$ .

Fig. 5 is built on the basis of dependence (4) by the way of determining the number of cutting lines  $i_t^{bl}$  from it based on the data of [19].

Based on the simple geometric determinations, the distance between the side edges of two adjacent blades according to the scheme of Fig. 4 can be determined by dependence (6):

$$\alpha_c^{bl} = 2h_{cr} k_s \text{ctg} \gamma, \tag{6}$$

where  $h_{cr}$  is the critical depth of blades cutting [19];  $k_s$  is the ratio of the depth of the soil guaranteed chipping zone to the critical depth of cutting ( $k_s = 0.9...0.95$ );  $\gamma$  is the angle of inclination of the side walls of the cut to the horizon (in cross-section) [20].

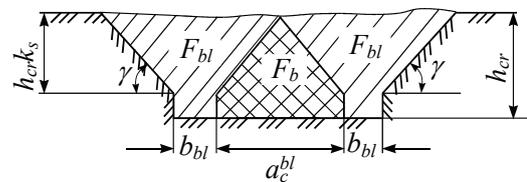


Fig. 4. Scheme for determining the distance between the side edges of adjacent blades

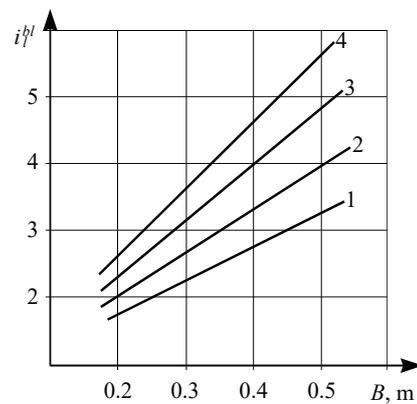


Fig. 5. Dependences of the number of blocked cutting lines on the width of the trench for semi-solid loam: 1 –  $\alpha_c = 20^\circ$ ; 2 –  $\alpha_c = 30^\circ$ ; 3 –  $\alpha_c = 40^\circ$ ; 4 –  $\alpha_c = 50^\circ$

The dependence of the technical performance of a multi-scraper trench excavator on the width of the trench in the semi-solid loam is shown in Fig. 6 ( $z_s^z = 1$ ).

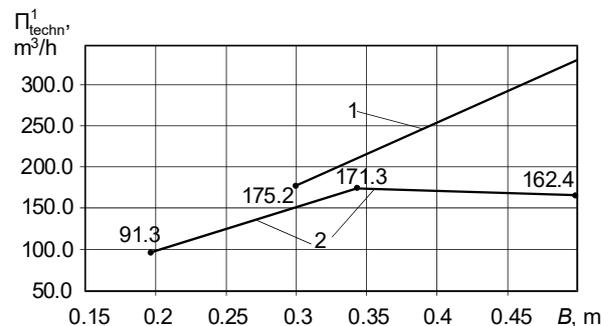


Fig. 6. Dependence of technical performance of a multi-scraper trench excavator on the width of the trench ( $z_s^z = 1$ ): 1 – for the width of the blades  $b_{bl} = 0.03$  m with the cutting angle  $\alpha_c = 30^\circ$ ; 2 – for the width of the blades  $b_{bl} = 0.02$  m with the cutting angle  $\alpha_c = 30^\circ$

The working speed (m/s) of the excavator depends on the technical performance and the cross-sectional area of the trench:

$$\vartheta_{e1} = \frac{\Pi_{techn}^1}{3,600BH} \quad (7)$$

The dependence of the working speed (m/s) on the cross-sectional area  $B \times H$  in semi-solid loam is shown in Fig. 7.

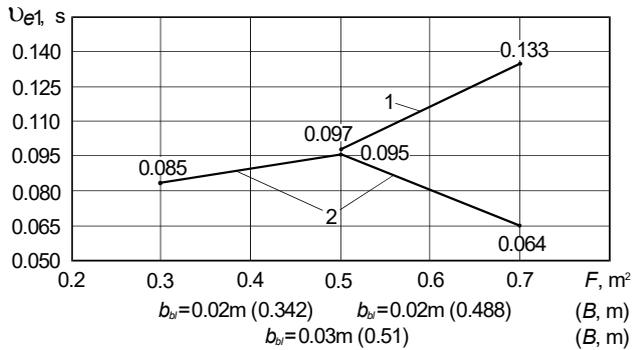


Fig. 7. Dependence of the working speed of the excavator on the cross-sectional area (width) of the trench ( $z_s^z = 1$ ): 1 – for the width of the blades  $b_{bl} = 0.03$  m with the cutting angle ( $\alpha_c = 30^\circ$ ); 2 – for the width of the blades  $b_{bl} = 0.02$  m with the cutting angle ( $\alpha_c = 30^\circ$ )

The angle between the velocity vectors of the working body  $\vartheta_e$  and soil cutting  $\vartheta_c$  is determined by dependence (8):

$$\beta = \arctg\left(\frac{\vartheta_s \sin \alpha}{\vartheta_s \cos \alpha + \vartheta_e}\right) \quad (8)$$

where  $\alpha$  is the angle of the working body installation to the horizon ( $\alpha = 30 \dots 55^\circ$ , preferably  $\alpha = 45 \dots 55^\circ$ ), deg [1, 7].

The time of soil cutting by a group of blades is determined by the cutting speed:

$$t_c = \frac{H}{\vartheta_c \sin \beta} \quad (9)$$

where  $H$  is the depth of the trench.

The absolute values of the critical depth for the middle and side blades are different. The middle blades of multi-scrapers trench excavators work in the conditions of symmetric blocked or semi-blocked cutting, and the edge side blades – in the conditions of asymmetric blocked or semi-blocked cutting. In [20], it was shown that the critical depth of cut for both symmetric and asymmetric cutting is directly proportional to the width of the blade. Therefore, the width of the edge side blades is determined by equating the critical cutting depth of the middle and side blades.

$$(a' - n'\alpha_c)b'_c = \frac{ab_{bl(nbl)}}{(\tg\alpha_c)^n k_s} \quad (10)$$

Hence:

$$b'_c = \frac{a \cdot b_{bl(nbl)}}{(\tg\alpha_c)^n k_s (a' - n'\alpha_c)} \quad (11)$$

where,  $b'_p$ ,  $b_{bl(nbl)}$  are, respectively, the width of the edge and middle blades;  $a'$ ,  $n'$ ,  $a$ ,  $n$  – respectively, the approximation coefficients for edge and middle blades, depending on the physical and mechanical properties of soils. The values of coefficients  $a$  and  $n$  are given in [19, 20], and coefficients  $a'$  and  $n'$  – in Table 1.

Table 1

Numerical values of approximation coefficients  $a'$ ,  $n'$

Type of cutting	Asymmetric locked		Semi-locked	
	$a'$	$n'$	$a'$	$n'$
Type of soil				
Soft-firm clay	4.02	0.046	6.70	0.076
Semi-solid clay	3.98	0.046	6.50	0.075
Semi-solid loam	4.26	0.050	6.69	0.079
Solid sand	5.02	0.066	7.26	0.093

For example, for semi-solid loam, the width of the edge side blades performing asymmetric blocked cutting is greater than the width of the middle blades:  $b'_c = 2,05b_{bl}$  for  $\alpha_c = 20^\circ$ ;  $b'_c = 1.74b_{bl}$  for  $\alpha_c = 30^\circ$ ;  $b'_c = 1.63b_{bl}$  for  $\alpha_c = 40^\circ$ ;  $b'_c = 1.63b_{bl}$  for  $\alpha_c = 50^\circ$ ;  $b'_c = 1.74b_{bl}$  for  $\alpha_c = 60^\circ$ .

### 7. Discussion of the results of the research on determining effective operating modes and sizes of excavator blades

The efficiency of chain-scrapers excavators is ensured by the minimum energy consumption of the working process and the maximum performance of the machine, which in turn depend on the shape of the blades, their number and arrangement.

It is known that when the blade starts cutting the soil at a critical depth, the energy consumption of the working process decreases, because the intensity of cutting resistance growth is less than the cross-sectional area of the cut. With the intensity of growth, the resistance of the soil to cutting with a blade increases because the soil presses into the side walls of the cut, and the area of soil breakage decreases because it is impossible to influence the process of day surface soil breaking. As a result, the energy consumption of the workflow increases.

Existing analytical and experimental models of interaction of multi-scrapers chain trench excavators with the soil do not determine the technological parameters of the machine, taking into account soil cutting at the level of critical depth. Thus, the existing recommendations on the machines design do not provide the minimum energy consumption and maximum performance of the workflow.

To substantiate the efficient operating modes of many scrapers excavators and the width of their edge side blades, the conditions of effective unloading were determined and the parameters of the dependence of the change in soil movement over the unloading scrapers surface on the unloading time were determined. For the same purpose, the dependences of the blocked cutting speed on the trench width were specified. After that, the technical performance of the excavator was evaluated on the basis of determining the soil bearing capacity of one group of blades operating in conditions of critical depth of soil cutting, taking into account the physical and mechanical properties of the soil. The special conditions allowed determining the width of the edge side blades carrying out asymmetric blocked soil cutting.

The obtained results take into account both the technological aspects of the excavator operation and the physical and mechanical properties of the soils excavated by the blades in the conditions of the critical depth of their cutting. This distinguishes the research conducted in the work from the previous ones. The obtained calculated dependences make it possible to take into account and analyze the main factors

influencing the processes of trenching and substantiate the parameters of the machine and its working equipment, which provide minimum energy consumption and maximum performance of the excavator taking into account physical and mechanical properties of soils. Thus, it can be claimed that an applied aspect of using the obtained scientific result is the possibility of improving the working equipment to create more efficient scraper trench excavators. The reduced energy consumption and increased performance are the important technical indicators that determine the cost not only of digging a trench, but also of laying linear-extended sections of underground distribution utilities in general.

## 8. Conclusions

1. It is determined that the time of unloading the soil from the scrapers very slightly depends on the angular speed

of a chain driving sprocket within its change  $\omega = 5.0 \dots 9.0 \text{ s}^{-1}$  in the zone of unloading. On this basis, the speed of blocked soil cutting by blades is determined depending on the width of the trench and the properties of different types of soils. It is determined that the speed of soil cutting with blades working at a critical depth is directly related to their width. For example, the increased width of the blade from 0.02 m to 0.03 m when digging a trench in the loam requires a 1.5 times reduction in the cutting speed.

2. The obtained calculation dependences for calculating the technical performance of the excavator based on determining the soil bearing capacity of one group of blades operating at a critical cutting depth made it possible to determine the width of the edge side blades performing asymmetric blocked cutting. For example, for semi-solid loam, it should be greater than the width of the middle blades and equal to:  $b'_c = 2.05b_{bl}$  for  $\alpha_c = 20^\circ$ ;  $b'_c = 1.74b_{bl}$  for  $\alpha_c = 30^\circ$ ;  $b'_c = 1.63b_{bl}$  for  $\alpha_c = 40^\circ$ ;  $b'_c = 1.63b_{bl}$  for  $\alpha_c = 50^\circ$ ;  $b'_c = 1.74b_{bl}$  for  $\alpha_c = 60^\circ$ .

## References

- Shatskiy, A. S. (2007). O sostoyanii mehanizatsii truboprovodnogo stroitel'stva. Truboprovodniy transport. Moscow: OAO VNIIST, 4, 10–14.
- Penchuk, V. A., Rudnev, V. K., Saenko, N. V., Suponev, V. N., Oleksyn, V. I., Balesniy, S. P., Vivchar, S. M. (2015). Soil thrust boring plant of static action with ring spacers of horizontal wells. Magazine of Civil Engineering, 54 (02), 100–107. doi: <https://doi.org/10.5862/mce.54.11>
- Kravets, S., Suponyev, V., Rieznikov, O., Kosiak, O., Nechydiuk, A., Klets, D., Chevychelova, O. (2018). Determination of the resistance of the cylindrical tubular drill for trenchless laying of underground communications. Eastern-European Journal of Enterprise Technologies, 3 (7 (93)), 64–70. doi: <https://doi.org/10.15587/1729-4061.2018.131838>
- Posmituha, O., Kravets, S., Suponyev, V., Glavatsky, K. (2018). Determination of equivalent and optimal sizes of wedge tip from flange for the static perforation of soil. MATEC Web of Conferences, 230, 01011. doi: <https://doi.org/10.1051/mateconf/201823001011>
- ESSO et le TCHAD. Mondialisation.ca. Available at: <http://www.internationalnews.fr/20-categorie-10189106.html>
- Chevron Pipe Line Company. Available at: <https://www.chevron.com/operations/transportation/chevron-pipe-line-company>
- The Natural Gas Pipeline Company of America. Available at: <http://www.frankkryder.com/assetmap.htm>
- Saudi Aramco – where energy is opportunity. Available at: <http://www.saudiaramco.com/en/home.html>
- Trans-Arabian Pipeline Company. Available at: <http://almashriq.hiof.no/lebanon/300/380/388/tapline/>
- Vermeer. URL: <https://www.vermeer.com/em>
- Trencor Introduces T14 Trencher Upgrade (2018). Available at: <https://www.americanaugers.com/trencor-introduces-t14-trencher-upgrade/>
- Cleveland Trencher Models. Available at: <http://www.cleveland-trencher.com/>
- Sobolevskiy, R., Korobiichuk, V., Levytskyi, V., Pidvysotskyi, V., Kamskykh, O., Kovalevych, L. (2020). Optimization of the process of efficiency management of the primary kaolin excavation on the curved face of the conditioned area. Rudarsko-Geološko-Naftni Zbornik, 35 (1), 123–137. doi: <https://doi.org/10.17794/rgn.2020.1.10>
- Palomba, I., Richiedi, D., Trevisani, A., Sanjurjo, E., Luaces, A., Cuadrado, J. (2019). Estimation of the digging and payload forces in excavators by means of state observers. Mechanical Systems and Signal Processing, 134, 106356. doi: <https://doi.org/10.1016/j.ymsp.2019.106356>
- Moczko, P., Pietrusiak, D., Wieckowski, J. (2019). Investigation of the failure of the bucket wheel excavator bridge conveyor. Engineering Failure Analysis, 106, 104180. doi: <https://doi.org/10.1016/j.engfailanal.2019.104180>
- Yu, X., Pang, X., Zou, Z., Zhang, G., Hu, Y., Dong, J., Song, H. (2019). Lightweight and High-Strength Design of an Excavator Bucket under Uncertain Loading. Mathematical Problems in Engineering, 2019, 1–12. doi: <https://doi.org/10.1155/2019/3190819>
- Musiyko, V. D., Koval, A. B. (2014). Vyznachennia sylovoho navantazhennia bazovoho shasi universalnoi zemleryinoi mashyny z vivalno-postupalnoiu podacheiu yii robochoho obladnannia na zabyi. Stroitel'stvo. Materialovedenie. Mashinostroenie. Seriya: Podemno-transportnye, stroitel'nye i dorozhnye mashyny i oborudovanie, 79, 133–140.
- Musiyko, V. D., Kravets, S. V., Pukhtaievych, O. I. (2018). Vyznachennia ratsionalnykh rezhymiv roboty intensyifikatoriv rozvantazhennia gruntu z robochykh orhaniv zemleryinykh mashyn bezpererвної diyi. Visnyk Natsionalnoho transportnoho universytetu, 1, 241–251.
- Kravets, S. V., Kosiak, O. V., Haponov, O. O., Yanchyk, T. O. (2019). Vyznachennia chysla liniy rizannia ta vysoty hruntotransportu- iuchykh skrebkiv lantsiuhovo-skrebkovykh transheinykh ekskavatoriv. U kn.: Budivnytstvo, materialoznavstvo, mashynobuduvannia. Intensyfikatsiya robochykh protsesiv budivelnykh ta dorozhnykh mashyn. Seriya: Pidiomno-transportni, budivelni ta dorozhni mashyny i obladnannia. Dnipro: DVNZ «PDABA», 66–74.
- Kosiak, O. V., Haponov, O. O., Pukhtaievych, O. H. (2018). Peredumovy stvorennia krytychnohlybnykh rezhymiv roboty bahatoskrebkovykh lantsiuhovykh transheinykh ekskavatoriv. Str-vo. Materialovedenie. Mashinostroenie. Seriya: Pod'omno-transp., stroit., dor. mashyny i obor., 103, 145–151.