STUDY OF WORKING BODY FOR REMOVING DAMAGED SOIL LAYER INSIDE CRATER

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Abstract. The article presents the design diagram and general appearance of the working body, which was mounted on an excavator boom to remove the damaged soil layer inside the pit. Based on the derived expression for determining the total cutting force that must be applied to the tines of the working body during their simultaneous interaction – taking into account the working body's speed while removing the damaged soil layer – graphical relationships were plotted. It was found that increasing the length of the tine b from 0.035 m to 0.055 m leads to an increase in the cutting force *P* by 46-52%. In this case, the cutting force *P* for the soil type – hard loam – increases by 2.1-2.3 times, and for semi-hard clay, it increases by 3.6-4.2 times compared to hard sandy loam. To conduct dynamic experimental studies in determining the soil cutting force exerted by the developed working body, an electronic dynamometer with an SBA interface was used, whose load cell was attached to the brackets of the working body. A comparison of the theoretical calculations and experimental studies revealed that the error between the obtained results lies within the range of 4.5-8.6%. Thus, based on the results of comparative studies, it was established that the preliminary calculation of the cutting force and energy consumption of soil cutting by the channel sections and angles of the working body adequately reflects the actual process of removing the disturbed soil layer within the excavation.

Keywords: working body, excavator boom, cutting force, excavation pit, damaged soil layer

Introduction

As a result of military operations, Ukraine's soil resources are suffering significant destruction, deterioration in quality and intensified degradation processes, with a range of mechanical, physical and chemical impacts on the soil cover. Such impacts lead to the destruction of the structure and functions of the soil ecosystem and result in the deterioration of its physico-geochemical properties [1-3]. All types of military-induced stress cause severe contamination and destruction of the soil cover. All types of munitions used in warfare are characterized by the generation of shock waves and explosive products that disperse into the environment. The agricultural sector of the economy, and in particular rural areas, suffers the most devastating impact of military operations, namely: damage to and destruction of the fertile soil layer due to the detonation of various types of explosive devices and the movement of military equipment, as well as contamination with harmful substances contained in explosives and fuellubricants, and the obstruction of agricultural land by destroyed military equipment, remains of fortifications, wood debris, etc. [4-6]. In addition to the direct destruction of the soil cover caused by the detonation of rockets, aerial bombs, artillery shells, and other explosive devices, a significant area of agricultural land has been mined, making it impossible to carry out agricultural work there [7-10].

To restore the topography of agricultural land, it is necessary to remove or clear the damaged soil layer from the crater, as it is chemically contaminated with heavy metals; furthermore, this process leads to the burning and dehydration of the fertile soil layer [11; 12].

Therefore, to remove the damaged soil layer from the centre of a crater formed by an explosion, it is proposed to use a new working attachment that is mounted on the excavator boom and enables the clearing process to be mechanised [13-16]. Subsequently, if a hazardous concentration of heavy metals and other hazardous substances is detected on the surface of the crater, the removed contaminated soil layer must be disposed of [17-20].

After this, the craters should be backfilled, ensuring the ground surface is levelled. In this way, technical land reclamation can be carried out [21-25]. Subsequently, it is advisable to carry out agrotechnical measures on the specified land plot, in particular disc harrowing and cultivation, and, if necessary, ploughing.

The purpose of this article is to develop a method for restoring agricultural land damaged by military operations to a condition suitable for use and for preserving soil fertility, through the use of a specially designed working tool capable of removing the damaged and contaminated soil layer from within a crater.

Materials and methods

To study the process of removing the damaged soil layer from the centr of a crater formed by explosions, an experimental prototype of a working body was manufactured.

The working unit consists of a frame in the form of rings, to which channels and angles are welded (Fig. 1). The welded structure is reinforced vertically with metal rings. A bracket is welded to the top of the working unit for attachment to the excavator boom, allowing it to swivel. The working unit is secured to the excavator boom using brackets. With the aid of a hydraulic system, the working unit can be rotated at an angle and turned about its own axis. Rotating the working unit makes it possible to adjust its angle of inclination relative to the surface of the pit, the surface layer of which needs to be cleared. The flanges of the channels and angles welded onto the working body will enable the top layer of the pit surface to be removed, thereby clearing it of damaged, melted soil containing heavy metals and other harmful substances.

a) b)

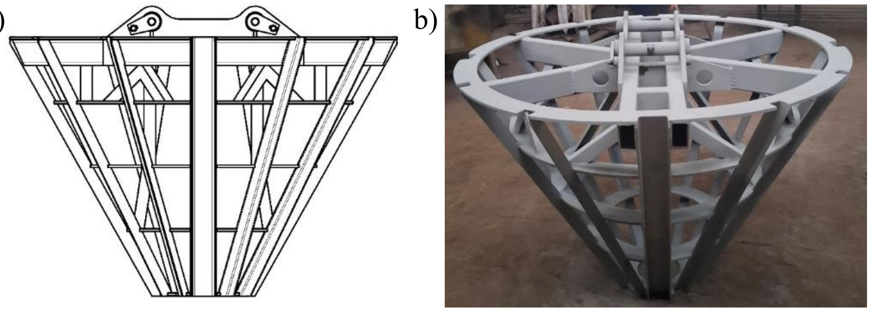

Fig. 1. **Schematic diagram (a) and general view (b) of the working body for scraping the damaged soil layer inside the pit**

During theoretical studies of the process of removing the damaged soil layer from the center of a crater, the influence of the working body's design parameters on the soil cutting force exerted by the channel sections and angle irons welded to the frame rings was determined. In [20], it was established that the destruction of the contaminated soil layer occurs due to shear and shear deformations following the disruption of the equilibrium of forces acting on the soil chip caused by the penetration of the flange of the angle iron or channel section. Destruction during shear deformation of the soil by the flanges of the channel sections and angle irons of the working body occurs with the working process being constrained by these vertical walls on one side of the flange. On the other side, the flange, when interacting with the soil mass, forms a slot with one-sided collapse. In this case, the flange performs blocked asymmetric cutting. The cutting depth *b* will be equal to the length of the channel and angle flanges of the working body, and the cutting length *l* will be equal to the length of the channel or angle. As a result of the rotation of the working body, shear deformation also occurs in the layer of contaminated, damaged soil that was located between the ribs of the angle and channel flanges.

In [20], an expression was derived to determine the total cutting force that must be applied to the flanges of the working body during their simultaneous interaction, taking into account the working body's speed during the removal of the damaged soil layer:

$$P_{\Sigma V} = n \cdot m \cdot b \cdot l \cdot \left(1.78 \cdot \varphi + \left(\frac{2 \cdot m_l}{m} + \frac{2 \cdot m_s}{m}\right) \cdot \frac{t}{l}\right) + \gamma_0 \cdot b \cdot l \cdot V^2 \cdot \tan\frac{\rho}{2}, \tag{1}$$

where φ – a coefficient accounting for the influence of the cutting angle;

m – a generalized measure of the soil's resistance to shear, compression, and internal friction during failure caused by cutting with a sharp blade, N·m^{-2};

m_l, m_s – coefficients characterizing the specific forces required to fracture the soil in the lateral extensions of the cutting face and to overcome the soil's shear resistance with the lateral working flanges, N·m^{-2};

t – thickness of the channel or angle flange, m;

b – cutting depth, equal to the length of the flanges of the channel sections and angle irons of the working body, m;

l – cutting length, equal to the length of the channel section or angle iron, m;

γ_0 – soil density;

V – working body travel speed during cutting; ρ is angle of internal soil friction.

To conduct field experiments on the process of removing the topsoil layer, the developed working body was mounted on the excavator boom using brackets. Research into the working process of removing the damaged soil layer inside the pit was carried out at the experimental field of the Institute of Mechanics and Automation of Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine in loamy soil with a 10-20% and soil particle cohesion within the range of 0.04-0.06 MPa.

To remove the surface soil layer, the developed working body was mounted on the excavator boom using brackets. Using the excavator's hydraulic system, the working body can be rotated at an angle and turned around its own axis. Rotating the working body allows the angle of inclination relative to the surface of the pit – whose top layer needs to be removed – to be adjusted. The flanges of the channels and angles welded onto the working body will enable the top layer of the pit surface to be removed, thereby clearing it of damaged, melted soil containing heavy metals and other harmful substances.

For conducting dynamic experimental studies, the working body was manufactured with the following parameters: height $H = 1$ m; diameter of the upper part $D = 1.5$ m; diameter of the lower part $d = 0.4$ m. The working elements were channel sections No.10 GOST 8240-97 and angle sections 45×45×5 GOST 8509-93, in which the flange width is $b_{fl} = 46$ mm and $b_{leg} = 45$ mm.

A diagram of the excavator's operation with the working body installed is shown in Fig. 2.

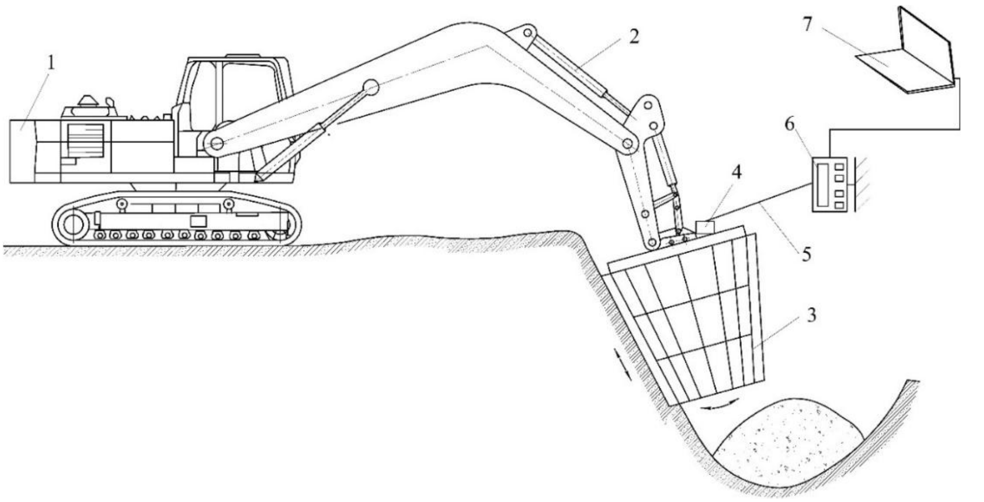

Fig. 2. **Diagram of the excavator's operation with the working tool for clearing damaged soil inside pits:** 1 – excavator; 2 – excavator boom; 3 – working tool; 4 – load cell; 5 – cable; 6 – electronic dynamometer; 7 – laptop

Fig. 3 shows general views of the load cell and electronic dynamometer used to measure soil cutting force.

a) b)

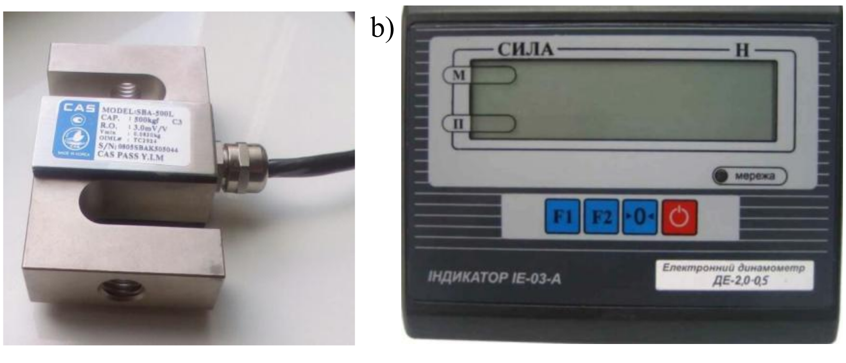

Fig. 3. **General views of the CAS SBA-a00L tensile-compression load cell CAS SBA-a00L (a) and the DE-2.0-0.5 electronic dynamometer (b), which were used to measure soil cutting force**

To determine the soil cutting force exerted by channels and angles, an electronic dynamometer with an SBA interface was used, the load cell of which was attached to the brackets of the working body. The dynamometer operates by converting the tension force of the cable into an electrical signal, which is processed by an electronic unit to display the tensile force on a digital indicator.

Fig. 4 shows a general view of the excavator with the working body and measuring equipment installed during the removal of a layer of soil.

Fig. 4. **General view of the excavator with the working body installed whilst removing a layer of soil**

The DE-2.0-0.5 electronic dynamometer can operate both in the mode of displaying the current force value and in the mode of recording the maximum force. The dynamometer measures the signal from the strain gauge, and the deformation caused by the applied force is converted into an electrical signal by a special sensor.

The dynamometer features a digital force display (display panel) and LED indicators for operating modes. Control is via a push-button keypad. All operations of the electronic dynamometer are managed by a microprocessor running a program stored in a read-only memory (ROM). Settings are stored in a reprogrammable ROM. The DE-2.0-0.5 electronic dynamometer can operate both in the mode of displaying the current force value and in the mode of recording the maximum force.

Fig. 5 shows a sequence of steps in the process of removing the damaged soil layer using the working body.

Fig. 5. **Sequence of the process of removing the damaged soil layer by the working body**

When the working body, to which a load cell is attached, removes the contaminated surface layer of soil, the electronic dynamometer converts the force into an electrical signal via the tension in the cable; this signal is processed using a dedicated programme on a laptop and displayed as an oscillogram on the monitor.

Results and discussion

Using Equation (1), graphs were plotted showing the variation in the cutting force required to be applied to the tines of the working body during their simultaneous interaction, taking into account the working body's speed while removing the damaged soil layer (Fig. 6).

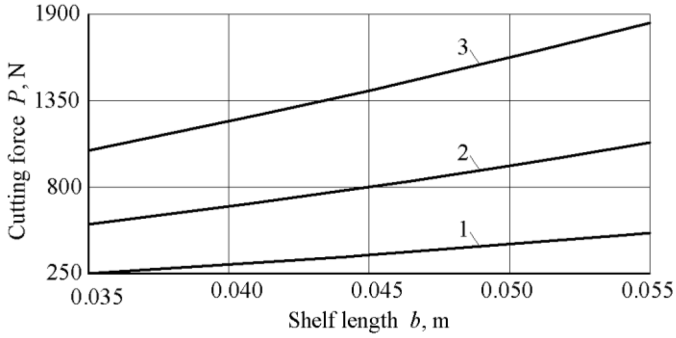

Fig. 6. **Dependence of cutting force *P* on changes in shelf length *b* for channel sections and angle irons with a length of *l* = 1 m for different soil types:** 1 – firm sandy loam; 2 – firm loam; 3 – semi-firm clay

It has been established that increasing the shelf length *b* from 0.035 m to 0.055 m results in a 46-52% increase in the cutting force *P*. At the same time, the cutting force *P* for hard loam increases by 2.1-2.3 times, and for semi-hard clay, it increases by 3.6-4.2 times compared to hard sandy loam.

In accordance with the adopted research methodology, field experiments were conducted to determine the cutting force. Fig. 7 shows the resulting oscillogram of soil cutting force values at a depth equal to the length of the channel section or angle bar of the working body, that is, 45 mm, for firm sandy loam, firm loam, and semi-firm clay.

During the studies, the cutting force values exerted by the flanges of the channels or angles of the developed working body were recorded whilst removing the surface soil layer in the centre of the pit, with ten repetitions.

A comparison of the theoretical calculations and the field experimental studies revealed that the error between the obtained results lies within the range of 4.5-8.6%.

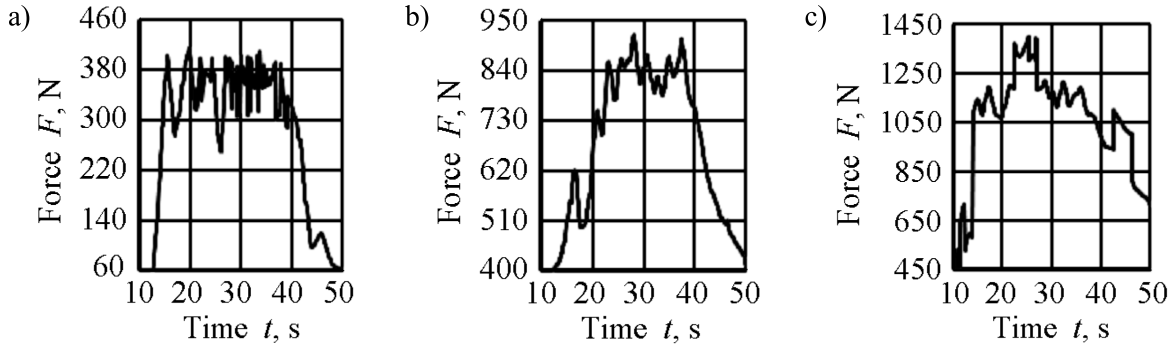

Fig. 7. **Oscillogram of cutting force values for different soil types:** a – firm sandy loam; b – firm loam; c – semi-firm clay

Thus, based on the results of comparative studies, it has been established that the preliminary calculation of the cutting force consumption of soil cutting by the flanges of channels and angles of the working body adequately reflects the actual process of clearing the damaged soil layer inside the pit.

The study of cutting force will not only determine the optimal design parameters of the working tool for clearing damaged soil inside craters, but will also enable the selection of an excavator to whose boom the developed working body is attached, and to determine the requirements for the engine, transmission, and fuel consumption based on the energy intensity of clearing one cubic meter of contaminated, damaged soil layer.

Conclusions

1. The article presents the design diagram and general appearance of the working body, which allows for field studies of the process of clearing the damaged soil layer from the centre of a crater formed as a result of explosions.
2. An expression has been derived to determine the total cutting force that must be applied to the tines of the working body during their simultaneous interaction, taking into account the working body's speed when removing the damaged soil layer. Using this, it was established that increasing the shelf length b from 0.035 m to 0.055 m leads to an increase in the cutting force P by 46-52%. In this case, the cutting force P for the soil type – hard loam – increases by 2.1-2.3 times, and for semi-hard clay, it increases by 3.6-4.2 times compared to hard sandy loam.
3. A methodology has been developed for conducting experimental studies of the working body for removing the damaged soil layer from the centre of the crater. Based on a comparison of the theoretical calculations and experimental studies, it has been established that the error between the results obtained lies within the range of 4.5-8.6%. Thus, the results of the comparative studies show that the preliminary calculation of the cutting force and energy consumption of the working body's channel sections and angles adequately reflects the actual process of clearing the damaged soil layer from the centre of the crater.

Author contributions

Investigation, O.T., validation, S.K.; data curation, O.T., S.K. All authors have read and agreed to the published version of the manuscript.

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