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Simulation of The Process of Destruction of The Array of Cambrian Clays By Cutters Actuating Device of Sinking Machinery In Terms of OJSC "Metrostroy", St. Petersburg

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Abstract

In the article the process of destruction of the array of Cambrian clays by cutting, as a dynamic contact problem of mechanics, solved with using the software environment ANSYS Worbench, is observed. The obtained results are verified on a laboratory bench setup with experimental investigations. Analysis of the results of computational and laboratory experiments shows that in the framework of theoretical and experimental approach to solving problems of continuum mechanics, as an integral part of the basic research a finite element method can be used, which lets adequately and with sufficient accuracy to determine the power and energy indicators of process of destruction of the clay arrays by cutting. A characteristic feature of the process of destruction of flooded Cambrian clays is significant plastic deformation of rocks at the contact with the cutter. The separation of the elements of destruction from the array occurs under the action of shearing stress by the formation of shear cracks. High viscosity of arrays of Cambrian clays defines a large share of energy consumption on their destruction, comparable in value to the energy intensity of the process of cutting of hard coal and salt rocks. The use of computer simulation can significantly reduce the duration and increase the accuracy of design calculations at designing of the actuating devices of mining machines.

Keywords: device, sinking machinery, process of destruction, simulation.

Introduction

The increasing pace of development of underground space Metropolitan cities necessitates increasing of the efficiency of construction equipment used in the construction of underground tunnels. The establishment of better heading machines, equipped with actuating devices of the new technical level, providing high performance and low specific power consumption when driving the main and auxiliary openings, can be implemented on the basis of the results of theoretical and experimental studies of the process of destruction of rocks.

In terms of OJSC "Metrostroy" (St. Petersburg) tunnel boring machines and complexes with the actuating devices of the cutting type found the greatest application. Construction production are mainly in arrays of moderately and weakly resistant, saturated with moisture layered clays formed during the Quaternary and the Cambrian geological periods and is characterized by significant variability of physico-mechanical properties, the presence of interbends, flooded areas and solids.

The study of the process of destruction of Cambrian clay by cutting, for the purpose of substantiation of rational parameters of actuating devices of heading machines is made by employees of the Department of mechanical Engineering National mineral resources university "University of mines", (St. Petersburg). The authors used a complex method of research, including the analysis of the main provisions of the fracture mechanics of rocks, the formulation of a computational experiment with subsequent verification of the results obtained on the laboratory bench installation.

Computer Simulation of The Cutting Process of Cambrian Clays

The most expansion at solving problems of continuum mechanics got the finite element method. Computer simulation of the cutting process of Cambrian clays allows to define the basic physical laws of deformation and destruction of rocks. At the same time, available in packages of engineering programs accurate description of the physic-mechanical properties of mountain ranges, anisotropic, heterogeneous media, characterized by the presence of initial stress-deformed state, seems to be very difficult, which causes the necessity to test the adequacy of the experimentally obtained results.

Modeling of process of destruction of Cambrian clay by single cutter is realized by facilities of ANSYS Workbench package. The algorithm of the computational experiment included the development of a virtual geometric models of destructible array and a single cutter, setting of source parameters and physic-mechanical properties of materials models, the formulation of assumptions and settlement. Given in the technical literature numerical indicators of physic-mechanical properties of the Cambrian clays vary in a fairly wide range [1, 2]. To determine characteristics of arrays of clays, relevant to conditions of OJSC "Metrostroy", Saint-Petersburg, the authors performed the sampling (depth ≈60 m) and laboratory tests according to the methods described in [3]. The results of the experiments are presented in table 1.

Table 1: Characteristics of the strength and deformation properties of Cambrian clay

№	Indicators of the strength and deformation properties	value
1	Density, kg/m^3	2250
2	The Young's modulus, Pa	$4,4 \cdot 10^9$
3	The Poisson ratio	0,35
4	Ultimate tension, mPa	1,8
5	Comprehensive resistance, mPa	15,4

The design of the simulated cutter is similar in parameters to the master cutter used to carry out experimental research by specialists IMA of Skochinsky. The cutting angle is of 60° end-clearance angle 10°, the cutting edge is rectangular with a width of 10 mm. Reduces of the width of the cutting edge in two times in comparison with the reference cutter caused by the strength characteristics of bench setup which was used to test the results of mathematical modeling. Material of cutter is steel 45 (45–50 *HRC*).

To evaluate the stress-deformed state of the simulated material the decision was taken: clayey array was considered a homogeneous, continuous and isotropic body. Boundary conditions were restrictions on movement imposed on the investigated model. The calculation was done at a depth of cut 10, 15 and 20 mm. The speed of movement of the cutter was set to a constant Vp=1.5 m/s, which corresponded to ranges of values of the conveying speed of cutters of existing actuating devices of heading machines. During the execution of the calculation 500 points was set (evenly distributed along the length of the cut), used for the monitoring and evaluation of the received data.

The main regularities of the formation process of loads on the cutters of heading machines were determined, primarily, by the peculiarities of the mechanism of destruction of rocks. Visualization of the distribution of stresses in the simulated sample allowed to determine the main directions of development of cracks, the angle of the lateral collapse of the cutting and settings detachable from an array of major elements (Figure 1).

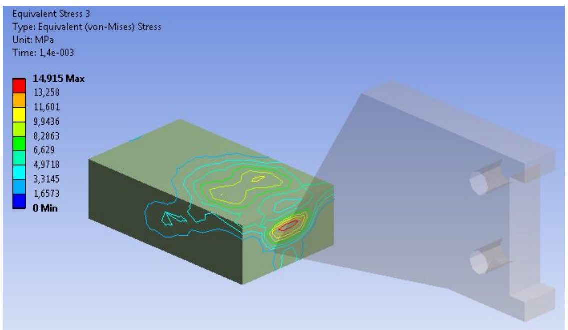


Figure 1: The distribution of isograms of normal and tangential stresses in the sample of Cambrian clay at the implementation of the single cutter

Waveforms of the process of destruction of the sample of Cambrian clay by single cutter, obtained by simulation in ANSYS environment, comply with the basic provisions of classic experimental-statistical theory of cutting (Figure 2).

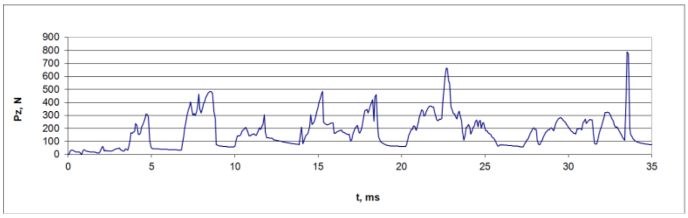


Figure 2: The waveform of the process of destruction of the sample of Cambrian clay by single cutter, depth of cut h=10 mm

Figure 3 shows an example of waveforms obtained as a result of experimental studies of the process of cutting of the sample Cambrian clay at h=10 mm.

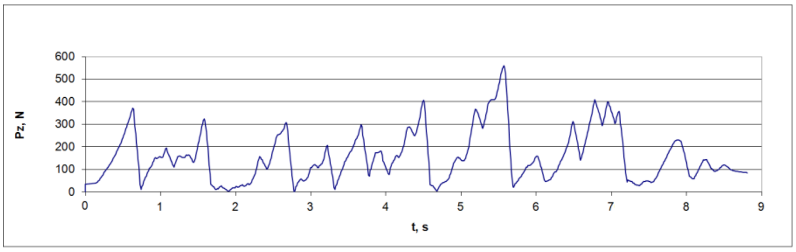


Figure 3: Waveform obtained as a result of experimental studies of the process of cutting of the sample Cambrian clay *h*=10 mm

Data processing was carried out using the methods of mathematical statistics: the well-known formulas were calculated dispersion and the expectation of cutting force. The calculation of these characteristics is made by the formulas

$$\overline{P}_z = n^{-1}\sum_{i=1}^{n} P_{zi}\ , \qquad (1)$$

where: $\overline{P}_z$ – mathematical average of cutting force, N; n – the number of intervals of discretization; P_{zi} – instantaneous value of cutting force in some point i, n.

$$D_x = (n-1)^{-1}\sum_{i=1}^{n}(P_{zi} - \overline{P}_z)^2, \qquad (2)$$

where: D_x – dispersion of the cutting force.

In the software package ANSYS Workbench provides the ability to measure the volumetric loss of the simulated sample after making the cut, which allows to calculate the specific energy consumption of the process of destruction of the clay array is provided. Calculation of specific energy consumption of the process is carried out according to the formula

$$H_w = 0,0272 \cdot \frac{\bar{P}_z \cdot L \cdot \rho}{G}, \quad (3)$$

where: H_w – specific energy consumption of the process of cutting, kW·h/m^3; L – length of the cut, cm; G – the weight of disintegration products , r; ρ – the density of Cambrian clay in the array, g/cm^3 [4].

The obtained values of power and energy parameters of the simulated process were recorded in the journal of studies (table 2) [5].

Table 2: Indicators of process of destruction of blocks of Cambrain clay, obtained by computer and laboratory experiments

Characteristic	Cutting depth *h*, mm	The result of computer simulation	Laboratory findings	The difference of resultes Δ, %
Cutting power P_z, N	10	133,0	153,3	15
	15	244,6	240,2	2
	20	444,8	407,0	8
The energy intensity H_w, kW·h/m^3	10	1,3	1,5	15
	15	1,05	0,9	14
	20	1,61	1,38	14
Dispersion D_x	10	14470,4	12412,7	14
	15	16026,2	75386,3	370
	20	34845,0	91140,2	161

Analysis of the results of computational experiments allowed to draw the following conclusions. A characteristic feature of the process of destruction of flooded Cambrian clay is significant plastic deformation of rocks at the contact with the cutter. The separation of the elements of destruction from the array occurs under the action of shearing stress by the formation of shear cracks. High viscosity arrays of Cambrian clays defines a large share of energy costs on their destruction, comparable in value to the energy intensity of the process of cutting hard coal and salt rocks.

Experimental Research

Verification of the results of computer simulation of the process of destruction of Cambrian clay by single cutter is made on a laboratory bench (Figure 4) of the Department of Mechanical Engineering of National mineral resources university "University of mines". As the actuator of bench setup the universal testing machine Zwick/Roell Z100,for which the accessory is designed and manufactured: a table with a clamping device for fixing the sample and holder with cutter, is used. Design and geometric parameters of the cutter correspond to the parameters by computer simulation. The transformation of the cutting forces into an electrical signal voltage is carried out by means of resistive strain gage DMS fixed on the measuring element of the testing machine Zwick/Roell and connected in a bridge circuit. Control of bench installation, and also visualization, preservation and data processing is done through software TestXpert II installed on a personal computer.

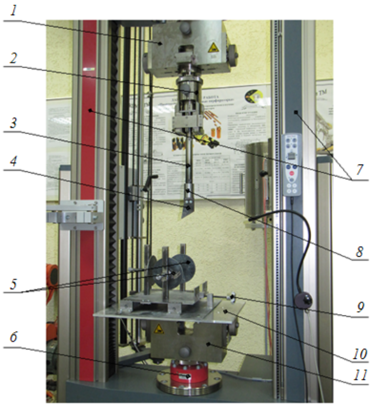


Figure 4: Bench for research of process of cutting of Cambrian clay by single cutter *1* – movable traverse; *2* – pendent carrier; *3* – rod; *4* – cutter; *5* – clutch; *6* – measuring converter; 7 – directional cross sections; 8 – cutter holder; 9 – screw-knob; 10 – table with a clamping device for fixing the sample of Cambrian clay; 11 – fixed cross head

Blocks of argillity thin-layer of sandy-clayey sediments were used as the samples. The type of cuts is blocked, of argillity of thin-layer of sandy-clayey sediments. The thickness of the chip is 10, 15 and 20 mm. Cuts were carried out in the direction across the strata. After the implementation of each cutting the collection and weighing of products of destruction was carried out, the shape of large items-chips was analyzed, the surface destruction was investigated.

Evaluation of the proximity of the process of fracture of blocks of clay by single cutter to the stationary was carried out according to the schedule of the density of the probability distribution of the values of cutting forces. The required confidence level of the results of experiments has been taken equal to 0.95 at a relative measurement uncertainty of 0.05. The analysis of power and energy parameters of the cutting process of Cambrian clay was carried out in five waveforms obtained under the same conditions. The experimental results were recorded in the journal of studies (Table 2) [5].

Analysis of the obtained data allows to make conclusion about satisfactory accuracy of the computer model of the process of destruction of clay by single tool, developed in the ANSYS Workbench. The difference between the results of numerical and laboratory experiments at determining cutting forces and specific energy of destruction does not exceed 15 %. Significant differences in the calculation of the variance of the loads on the cutter explains the small number of control points on the cut length and the presence of assumptions about homogeneity and isotropy of the material when conducting computer simulation. Almost linear nature of the graph of changes of cutting force, $P_z(h)$ with increasing thickness of the depth of cut (Figure 5 a) corresponds to the classical theory of cutting rocks. At the same time, the graphs of the variation of energy intensity of destruction clay $H_w(h)$ by single cutter have expressed extreme minimum at the chip thickness h=14-16 mm and monotonically increase with increasing cutting depth over these values (Figure 5 b), which differs significantly from the exponential dependency $H_w(h)$ obtained for coal and fragile rocks and presents technical literature [4].

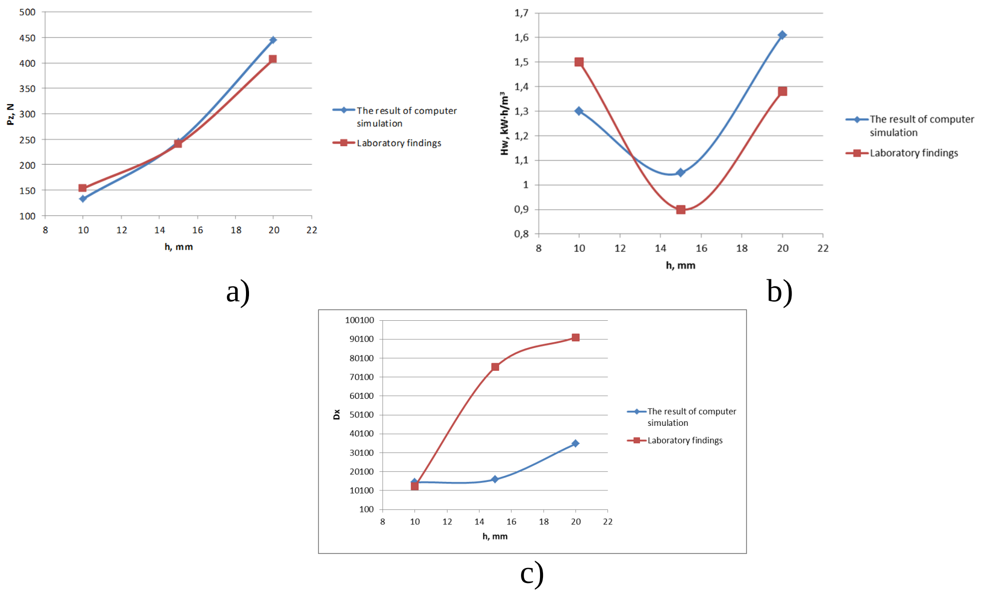
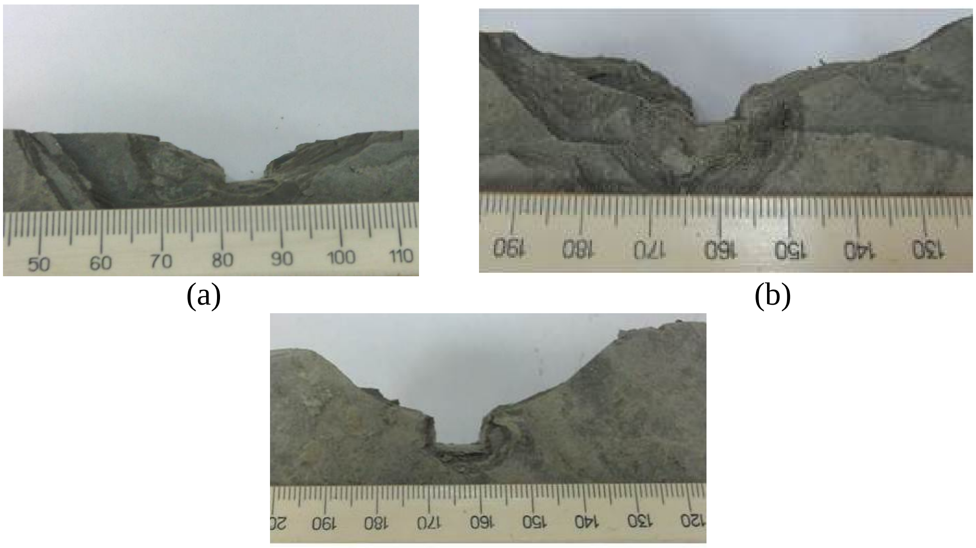


Figure 5: Graphics of power and energy characteristics of the process of destruction of samples of Cambrian clay by single cutter: a) the dependence of the cutting force on the depth of cut; b) the dependence of the change of storage density of the process of cutting from the depth of cut; c) the dependence of the dispersion of the loads of the cutter from the depth of cut

This feature of the cutting process is explained by the high viscosity of clay and significant inelastic deformations accompanying the implementation process of rock cutting tool in the array. The study of the surfaces of the cuts in samples of Cambrian clay and form of large spallings revealed the following regularities.

It is known that the process of cutting brittle rocks is cyclical in nature, accompanied by the crushing of rock, the formation of core compaction of fine dust and separation from the array of consecutive elementary spallings. [4, 6]. The process of destruction of Cambrian clay by cuts of small thickness (h≤15 mm) is similar to the cutting of brittle rocks. The spallings are well defined, separated from the array semicircular fractures. Lateral collapse is formed on almost the entire depth of cut. (figure 6 a). The bottom surface of the cut is uneven, characterized by the presence of numerous induced defects and discontinuities. With increasing of depth of cut the profile of the cuts, carried out in samples of the clay, changes. The bottom of cuts and side surfaces intersect almost at right angles, the collapse of the cut is not formed to the full depth (Figure 6 b). Separation of large items from the array is carried out through the cracks of the shift, the development of which is accompanied by significant plastic deformation of the stone. Thus, a significant portion of the energy supplied to the rock cutting tool, is spent on overcoming the inelastic force-deformation clay of the array, and not on the formation of new fracture surfaces, which negatively affects the value of specific power consumption of the cutting process.



(a) (b)

(c)

Figure 6: The structure of the surfaces of the cuts in the destruction of the samples of Cambrain clay by single cutter: a) *h*=10 mm; b) *h*=15 mm; c) *h*=20 mm

The magnitude of the plastic deformation is determined by the level of natural moisture samples of Cambrian clay, with the help of the scheme of cutting and geometric parameters of the rock cutting tool. During laboratory experiments it is established that on the flat front edge of the used cutter a dense growth of adhered fine dust, reducing the cutting angle of the cutter and not collapsing at implementing of subsequent cuts is formed. Jamming of cutters negatively affects the productivity of the tunnel shields and increases the load of the drive elements of mining machines.

Conclusion

Analysis of the results of computational and laboratory experiments shows that in the framework of theoretical and experimental approach in solving of problems of continuum mechanics, as an integral part of the basic research finite element method can be used, which lets adequately and with sufficient accuracy to determine the power and energy indicators of process of destruction of the clay arrays by cutting. The use of computer simulation can significantly reduce the duration and increase the accuracy of design calculations at the design of the actuating devices of the tunnel shields. In the course of the research it is established that the process of destruction of arrays of Cambrian clays by cutting is characterized by high specific energy, which is explained by the high viscosity of clay rocks. Factors that have a negative impact on the efficiency of the cutting process are the high water content and accumulation of clay on the cutting tool (jamming of cuttings).The dependency analysis of the changes of power and energy characteristics of the cutting process, resulting from holding calculations and laboratory experiments, allows to conclude that the destruction of clay arrays is efficiently to implemented by cuts of small thickness at high speeds of cutting.

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