RATIONALE FOR THE PARAMETERS OF BORE HAMMER FOR TUNNELING THE SERVICE ROADWAYS IN CAMBRIAN CLAYS

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ABSTRACT

The article deals with the issue of mechanization of operations during tunnelling the service roadways over argillaceous arrays in course of construction of subway networks. Design of the bore hammer is presented; whose construction allows to work in striking and striking-rotary modes. Results of experimental studies to determine the main parameters of suggested striking operating tool are given, and calculation is performed and the graph is built for productive capacity of the blade shield unit equipped with suggested operating tool.

INTRODUCTION

Underground urbanization is developing intensively worldwide. Underground construction accompanies development of large cities. It is impossible to imagine modern cities without underground structures in forms of subway, sewers, walking tunnels, road junctions, garages and premises of different purposes. The intensity of development of underground space depends on multiple factors; one of determining factors is the nature of landscape and geological and hydro-geological conditions of the city (Protosenia, *et al.*, 2011; Dashko, *et al.*, 2011).

Constant growth in demand for tunnels in the cities is, in turn, one of the main engines of development of tunnel technologies and particularly engine-driven penetration. All over the world, in contemporary urban underground subway construction, the highest priority belongs to various shield techniques: engine-driven and automated blade shield units for creating tunnels of various shapes and cross-sectional dimensions at various geological conditions.

METHODOLOGICAL FRAMEWORK

Based It has been found that the shield method of works has number of advantages over the mining method. Therefore, about 500 shields are manufactured worldwide annually, most of which are engine-driven (Gulelmetti, *et al.*, 2013; Brenner, *et al.*, 2009). Certain specific types of modern blade shield units cannot be attributed to any particular category of equipment: those units are often created specifically for use in very difficult terrain and heterogeneous geological conditions. In fact, these shield units are featured both for use in the soft grounds (featuring the monitoring over ground subsidence and collapse prevention), and for penetration into rocky ground, and have all necessary elements for that. The first example of such a unique unit has become the shield with water weight, used for penetration of the tunnel within EOLE Project in Paris, when the work was carried out in sands, marls and limestone. We should also mention the blade shield with soil weight, used for penetration of the tunnel of the subway tunnel in Porto city, when it was necessary to work in different

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grounds-from eluvia deposits to fractured granite of Porto formation (Protosenia, *et al.*, 2011).

Engineering and geological conditions in Saint Petersburg are characterized by a great heterogeneity and relative complexity, which should be considered when using the city's underground space. Tunnels and boreholes network of the Saint Petersburg Metro is located at a depth of 40 m to 70 m; therewith, the construction of the tunnels is accompanied by penetration of the service roadways (Yungmeyster, *et al.*, 2014; Yungmeyster and Isaev, 2016) (transport and auxiliary wireline passes, blind and specialized workings, workings of shaft inset, chamber etc.), required for connection of stations under construction with a vertical shaft, for the output of fragmented rock to the surface, for delivery of everything necessary for construction of stations. Often, in course of development of such workings blade shields and bore type units are not applicable, so, their development all over the world is carried out using manual labor of shaft men with jack-hammers and fastening of the mine face with timber. In course of penetration, workers stand in dangerous untimbered area near a face of the hole; moreover, this type of penetration has relatively small productive capacity. Thus, in order to improve the safety and efficiency of penetration of service roadways in argillaceous bottom holes, it turns out necessary to implement the engine-driven blade shield units.

Tunneling service roadways closely to the Saint Petersburg Metrostroistations under construction should be based on equipping of tubing or beam setter with operating tools in their erector, in order to enable breaking and fastening of the processed array. Due to the fact that bottom holes of the Saint Petersburg Metrostroi stations have structure varying in composition: from the dry clay with hardness factor of 1-2 on prof. M. M. Protodiakonov scale, to the clays with solid inclusions, the destruction of which by means of the chopping tool is virtually impossible, for penetration in such conditions, application of striking type operating tools is reasonable; however, hydraulic drills with independent strike and rotation work with water removal of the spalls from bottom hole, which is not applicable for clays. Industrial prototypes of pneumatic bore hammers with a significant striking energy are not represented at the mining industry market, however, the manual tools, capable of operating in both bore hammer and drill modes, are represented in very extensive range. We have developed and patented the design of striking operating tool for blade shield unit (Fig. 1 and 2) (Yungmeyster, *et al.*, 2016).
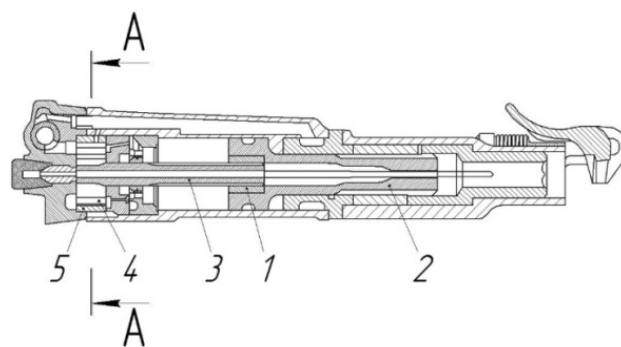

Fig. 1 Schematic depiction of bore hammer, longitudinal section.

Hammer of the operating tool is equipped with a swing gear of pike in form of helicoidal couple consisting of rifle nut 1 (Fig. 1) fixed inplunger-hammer 2 and shank 3 with helicoidal thread and latching's 4 (Fig. 2) and ratchet wheel 5, located in the case 6of hammer (analogue-ПП54В). Latching sallow the shank 3 to rotate only in one direction.

Ratchet wheel, according to the patent (Yungmeyster, *et al.*, 2016), is made sectional and consists of individual segments 7 (Fig. 2). Between the segments of the ratchet wheel and casing, the pivots 8 are located. The trigger valve 9 of compressed air is installed in the casing (Fig. 2), and the rubber gaskets 10 are located between the segments of the ratchet wheel. Each segment can move in the radial direction under the action of compressed air fed into the cavity between segments and casing or under the action of the elastic forces of the springs 8 (Fig. 2).

Under normal conditions, percussion drilling is used. Segments of the ratchet wheel are driven apart (Fig. 2b) and held in that position by non-deformed springs. Rubber gaskets overlap the gaps between segments, and latching's are disengaged with gear teeth of the ratchet wheel, ensuring transmission of only impact momentum to the rock-breaking tool. Hammer operates as a jack-hammer.

However, during drilling-off of the bottom hole, the hitting of rock-breaking tool on water flooded sections of array is possible, which in future may lead to its jamming. In this case, the trigger valve is opened and compressed air is fed into the space between the segments of sectional ratchet wheel and its casing. Under the action of compressed air pressure force, the segments are moved (Fig. 2a), pivots are stretched, the ratchet wheel becomes a single entity and is held in this position by compressed air pressure, and latching's are engaged with gear teeth of the ratchet wheel. The hammer starts operating as a perforator, i.e. impact momentum is transmitted to the pikes,
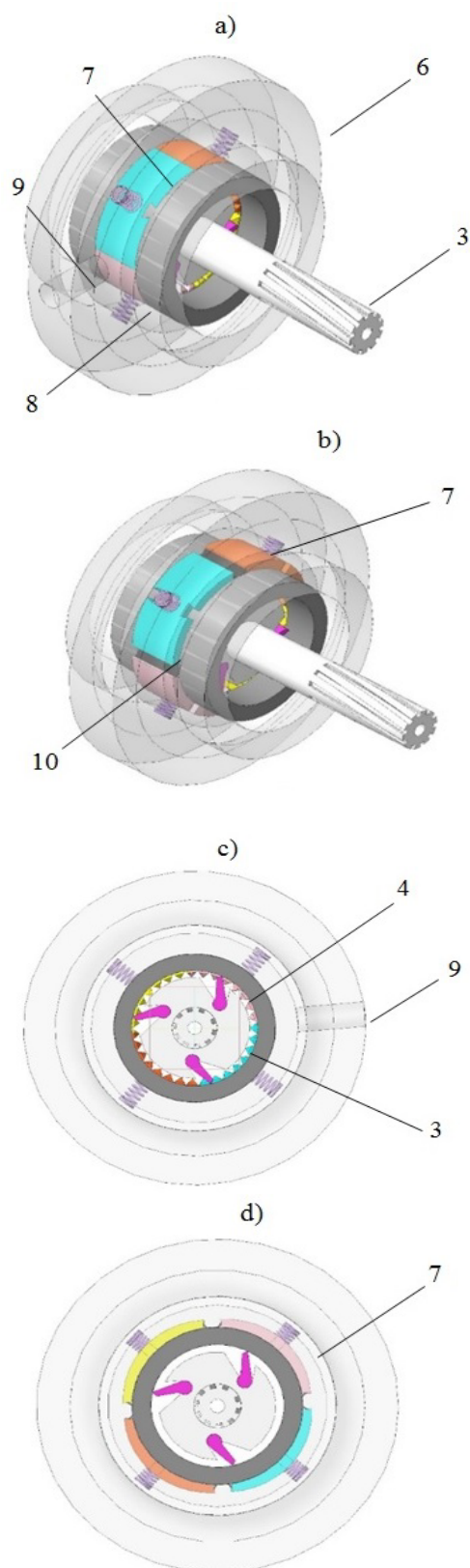
Fig. 2 Model of helicoidal sectional ratchet mechanism, A-A section: a) axonometric view of ratchet wheel in closed position; b) axonometric view of ratchet wheel in open position; c) view on A-A section, ratchet wheel in closed position; d) view on A-A section, ratchet wheel in open position.

and their rotation is provided, which promotes fast destruction of the solid inclusions.

The important factors to reduce the energy intensity of the process of rock destruction are tool geometry and form of the impact momentum; in order to determine design of rock-breaking body of striking operating tool of the blade shield unit, we have developed the facility and conducted experimental research. Determination of correspondence of punching-in the rock-breaking tool into array of Cambrian clay was carried out using stand No.1 (Fig. 3), represented by a vertical pile driver (Isaev, 2015).

RESULTS AND DISCUSSION

On the base frame of experimental stand, we have mounted the pilot pins, on which, forced by gravity, moves the drop with the pike installed in it. During the experiment, test sample Cambrian clay is placed on the base frame; after that, the drop is raised to the pre-calculated height, and after that it is retained. At removal of fixation of falling element (drop), it, being
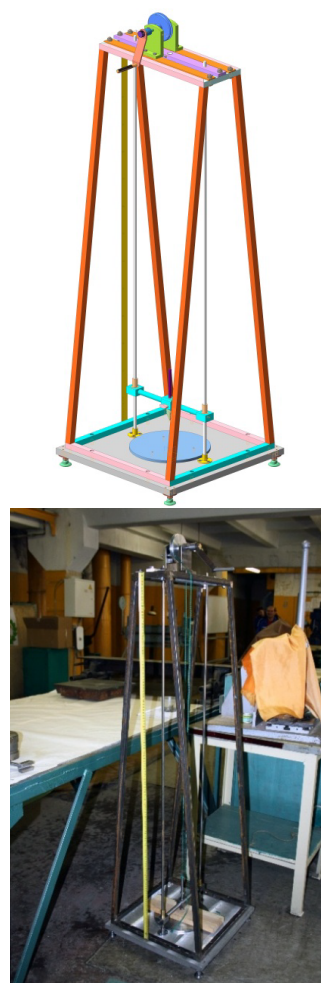

Fig. 3 Vertical pile driver: a) assembly drawing of 3D model; b) overview.

forced by gravity, strikes test sample of Cambrian clay. After delivering single strikes and sequence of them, measurement of the hole depth is performed using beam trammel.

As a result of the first series of experiments, the correspondences were obtained, between average landing of the pike with various cutting angles into the samples of Cambrian clay, and the number of strikes (n) for various cutting angles of rock-breaking tool and energies of delivered strike (A_{str}) (Table 1).

Values of approximation reliability R^2 for each regression equation have the following (Fig. 4):

$$R_1^2 = 0,9799, R_2^2 = 0,9236, R_3^2 = 0,9573.$$

Table 1 shows that the curves=$f(A_{str})$, characterizing the change in productive capacity of process with increasing the striking energy for various cutting angles of rock-breaking tool, are described by power-law dependences with close values. The largest value of landing was received when using of rock-breaking

tool with 30° cutting angle. Further experimental studies (the second cycle) were conducted for the cutting angle equal to 30°(Isaev, 2015).

As a result of the second series of experiments, the correspondences were obtained, between average landing of the pike with cutting angle equal to 30° into the samples of Cambrian clay, and the number of strikes.

Obtained correspondences between the pike landing into the samples of Cambrian clay, and the number of delivered strikes with different striking energy are described by power functions with exponents within the range of 0.37 to 0.40. Correspondences show that upon delivering further strikes, the value of punching-in of rock-breaking tool into the clay samples is decreased; this situation is associated with fact that compacted ellipsoidal areas of deforming rock are being formed ahead of the tool.

Considering the obtained correspondences, and having introduced some assumptions listed below,
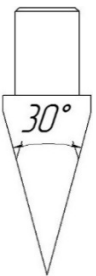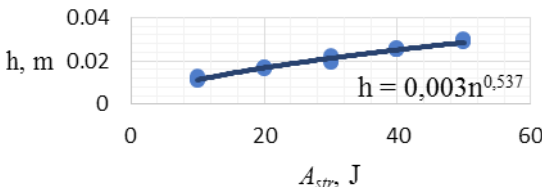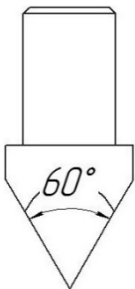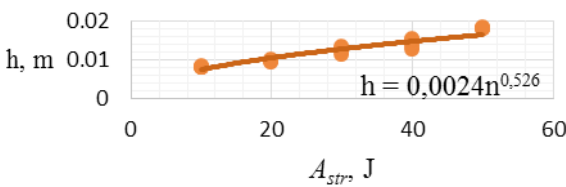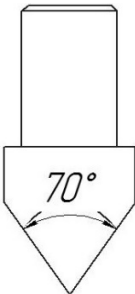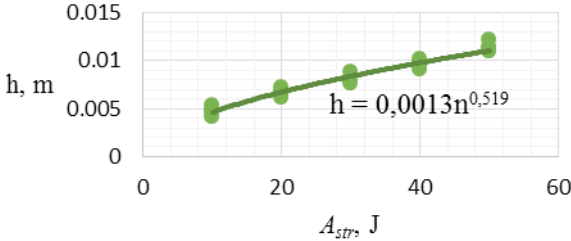
Shape of rock-breaking component	Dependency of landing value
30°	$h=f(A_{str})$ $h = 0,003n^{0,537}$
60°	$h=f(A_{str})$ $h = 0,0024n^{0,526}$
70°	$h=f(A_{str})$ $h = 0,0013n^{0,519}$

Table 1. Depending on the average penetration peaks at different angles sharpening.
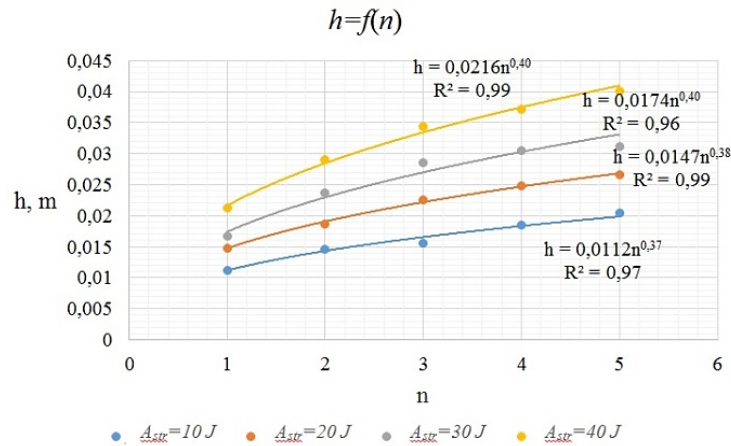
Fig. 4 Correspondences between average landing of the pike with cutting angle of 30° into the samples of Cambrian clay, and the number of strikes.

theoretical productive capacity of blade shield unit, equipped with striking operating tool shown at Fig. 1 and 2, has been calculated.

1.   Volume of Cambrian clay chipping fits into a regular polyhedron, namely triangular pyramid (Fig. 5), which has a square dihedral angle at one of the edges of the pyramid's base line, and a length (h') of one of the three side surfaces is described with formula, depending on initial landing of the pike h_0:

$$h' = h_0 \cdot n^{\hat{a}} = \left(\sqrt{\frac{A_{str}}{Z \cdot d \cdot \acute{o}_{comp} \cdot (g \, \frac{\hat{a}}{2} + \grave{i}) \cdot K}} \right) \cdot n^{\hat{a}}$$

Where A_{str}-striking energy, J; d-diameter of the pike, m; σ_{comp}-limit compressive strength of rock, MPa; α-cutting angle of the pike, degrees; μ –coefficient of friction between tool and rock; K-blunting factor of the pike's cutting edge; n-number of strikes delivered, pcs.; n_{str}-frequency of jack-hammer strikes, sec.[-1]; β-exponent of change in landing of the pike.

Exponent β depending on striking energy and cutting angle of rock-breaking tool has been determined experimentally and its range of values equals 0.37 to 0.40 (Isaev, 2015).

Chipping occurs in time equal to the full landing of rock-breaking tool (h_Σ), $t = n/n_{str}$;

Increase in hardness of processed bottom hole affects the decline in h_0;

Facility of processed bottom hole allows obtaining the chipping much faster, due to growth in speed of rock-breaking tool landing.

As a result of change, volume of initial chipping V_{ch} (m³) can be calculated by the following formula:

$$V_{ch} = \frac{\sqrt{3}}{2} h_0^3 n^{3\hat{a}} = \frac{\sqrt{3}}{2} \cdot \left(\sqrt{\frac{A_{str}}{Z \cdot d \cdot \acute{o}_{comp} \cdot (g \, \frac{\hat{a}}{2} + \grave{i}) \cdot K}} \right)^3 n^{3\beta}$$
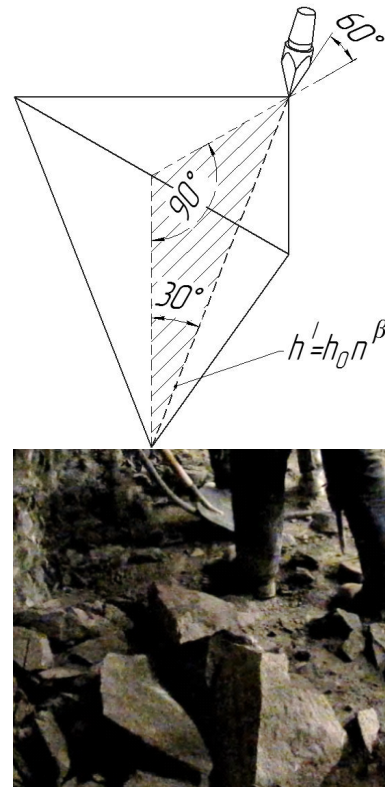

Fig. 5 Volume of Cambrian clay chipping: a) in form of geometric shape; b) photo of the chipping slab in the bottom hole.

Herewith, the formula of theoretical productive capacity (Q_{theor}, m³/sec) considering strike frequency of a jack-hammer (n_{str}) will be as follows:

$$Q_{theor} = \frac{\sqrt{3}}{2} \cdot \left(\sqrt{\frac{A_{str}}{Z \cdot d \cdot \acute{o}_{comp} \cdot (g \, \frac{\hat{a}}{2} + \grave{i}) \cdot K}} \right)^3 n^{(3\hat{a}-1)} \cdot n_{str}$$

Results of blade shield unit's theoretical productive capacity calculation by above given formula are shown at Fig. 6.
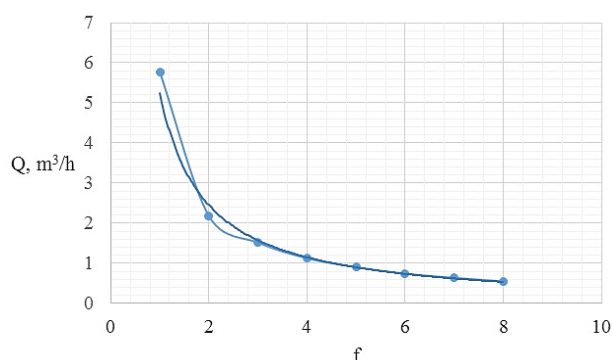
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Fig. 6 Dependency diagram of correspondence between productive capacity of blade shield unit equipped with striking operating tool and the hardness of processed array.

CONCLUSION

Applying the developed design of bore hammer in the operating tools of units for running service roadways at the boreholes of the Saint Petersburg Metrostroi allows increasing productive capacity and quality of bottom hole processing, due to using the tool having the proper shape of an active zone, exception of the tool (jack-hammers of the pikes) jamming, and increase in productive capacity of breaking. Therefore, implementation of the units based on tubing setters into the service roadways construction will enable to significantly reduce the share of manual labor in tunneling and to shorten the construction periods of new Metrostroi facilities.

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