The design of the guide frame of the tunneling shield for laying communications under the riverbed

A B Letopolsky*, P A Korchagin and I A Teterina

Siberian State Automobile and Highway University (SibADI), 644089, Omsk, Mira Ave., 5 Russia

*Antoooon-85@mail.ru

Abstract The article presents the option of improving the working equipment of the tunnel-boring complex for laying underground utilities, including trunk pipelines. The method of trenchless laying of underground utilities, consisting in a combination of methods of horizontal directional drilling and micro-channeling, is proposed. The proposed technology does not require the construction of a preliminary mine and a site for the installation of a drilling machine and allows one to combine in one working step the drilling of a well, the laying of a pipeline, welding and insulation works. Presents calculations aimed at determining the forces of movement of the shield, the definition of the power of the shield, as well as the calculation of the strength of the shield. The technique of carrying out technological operations is demonstrated taking into account the use of the proposed technical solution.

1. Introduction
The exploration and development of underground space is an up-to-date construction technology at a time when, in order to preserve mobility, an overwhelming number of infrastructure facilities specifically diverted underground. This applies not only to tunnels and collectors, but also to the laying of underground utilities.

Construction and laying of underground communications can be carried out in two ways: open and closed. An open way entails damage to the earth’s surface, excavating a trench, stopping traffic and causing environmental damage. This makes the open way of development unprofitable [1].

A more promising is the second method of development, requiring minimal opening of the earth’s surface, using specially designed machines. Such a technology includes a tunneling shield, installation for horizontal directional drilling [1]. Such tunneling machinery guarantees high accuracy of the work performed, since it is controlled by high-precision, technological navigation devices. This makes trenchless laying one of the main ways of laying communications.

Despite the advantages of the closed method of laying underground communications, there are a number of shortcomings that need to be addressed using new technological and engineering solutions that ensure high safety and efficiency of construction.

2. Researching
To ensure the successful implementation of many projects, taking into account the minimum cost, an installation was proposed that does not require the construction of preliminary mines and a large area for the installation of a drilling machine and allows one to combine the drilling of a well, the laying of a pipeline, welding and insulation [2].
In order to increase the productivity of the work, it was proposed to replace the jacking station with a universal pushing frame (Figure 1). At the same time, no changes are made to the design of the tunnel-penetrating shield. This solution will allow you to control the trajectory of the pipes. In addition, removes the need for construction of the starting and acceptance pit [3,4].

![Figure 1. Guide frame](image)

The proposed design includes: 1. frame; 2 - hydraulic grip; 3 - mobile platform; 4 - roller; 5 - hydraulic motor; 6 - gear; 7 - the valve; 8 - hydraulic hoses.

Installation and consists of a frame resting on a concrete base. With the help of hydraulic motors (5), an additional frame of coupling elements is moved in front of the mobile carriage (3). The frame of coupling elements leans on a gear wheel (6). On the frame (1) are fixed hydraulic claws (2) that cover the pipe and impart traction to it. On hydraulic hoses (8), liquid from hydraulic motors and hydrocylinder enters the hydraulic distributor (7). On each side, the pipe is additionally supported and guided by rollers (4). Hydraulic motors are located on the moving platform (3), which set it in motion. Movement is carried out on the gear racks located on the frame (1).

To determine the required power of the jacks, ensuring the movement of the shield, the required forces were calculated.

The condition for the movement of the shield [5]

\[
F \geq R \cdot \frac{\gamma_p}{\gamma_n}
\]

(1)

where \(F\) and \(R\) are the calculated values, respectively, of the force of movement and the total resistance to the movement of the shield, kN; \(\gamma_p\) and \(\gamma_n\) are the coefficients of working conditions and reliability, for sands and rocks, \(\gamma_p = 1\), \(\gamma_n = 0.95\).

The total resistance to the movement of the shield, surmountable shield jacks, is determined on the dependence basis [6]

\[
R = R_1 + R_2 + R_3 + R_4
\]

(2)

where \(R_1\) - resistance to the introduction of the head of the shield in the rock, kN; \(R_2\) - resistance (friction force) on the outer surface of the shield body, kN; \(R_3\) - resistance (friction force) on the inner surface of the shield shell and the outer surface of concrete rings, kN; \(R_4\) - resistance moving together with the shield on the lining of the part of the tunneling technological complex, kN.
In the case of partial incision of a knife ring into resistant clay rocks (dense clays, loams), the development of the central part of the face is carried out before the shield moves. The penetration force \( R_1 \) of the head of the shield in the face is determined by the specific force of cutting the knife into 1 meter of its perimeter length. In this case, \( R_1 = 40 \text{ kN} / \text{m} \).

The resistance \( R_2 \), that occurs when overcoming friction forces, the outer surface of the shield body on the rock, is determined by the formula [6,7]

\[
R_2 = \mu_1 \cdot [2 \cdot (q + p_a) \cdot L_s \cdot D_s + G],
\]

where \( \mu_1 \) - coefficient of friction of steel on rock, \( \mu_1 = 0.38 \ldots 0.55 \); \( q \) and \( p_a \) are the vertical and horizontal loads from the thickness of rocks above the tunnel in natural occurrence and from the pressure of the rock; \( L_s \) - the length of the body of the shield; \( D_s \) - diameter of the body of the shield; \( G \) - shield gravity, \( G = 100 \text{ kN} \).

The resistance \( R_3 \) arising in overcoming the friction forces of the inner surface of the shield shell along the outer surface of concrete rings is determined by the formula [6,8]

\[
R_3 = G_{fg} \cdot \mu_2,
\]

where \( G_{fg} \) - gravity of concrete rings inside the shield shell, kN; \( \mu_2 \) - coefficient of friction of the concrete-steel pair \( \mu_2 = 0.4 \ldots 0.5 \).

Under the shell of the shield, 2.2 meters in length, the elements of concrete rings made of reinforced concrete tubings, whose length is 1.0 meter, are placed. Own weight of concrete rings can be determined by the specific gravity of the material and its geometric dimensions.

For reinforced concrete rings in stable rocks, a weight of 1 m\(^2\) (kN) is determined by the formula [9]

\[
g = 1.9 \cdot r_n,
\]

where \( r_n \) - outer radius of concrete rings, m.

If the weight of 1 m\(^2\) is \( g = 1.9 \text{ kH} \), then the own weight of the concrete ring that fits under the shield shell is calculated [9]

\[
G_{fg} = g \cdot L.
\]

The resistance \( R_4 \) to the movement of a part of the tunnel complex together with the shield is determined by the formula [6,8]

\[
R_4 = G_{nk} \cdot \mu_2 \cdot k_{mc},
\]

where \( G_{nk} \) - gravity of the part of the tunnel complex moving with the shield, \( G_{nk} \approx 730 \text{ kN} \); \( k_{mc} \) - coefficient taking into account possible local resistances to the movement of elements of the tunnel complex, \( k_{mc} = 2 \); \( \mu_2 \) is - coefficient of friction of the concrete-steel pair \( \mu_2 = 0.4 \ldots 0.5 \).

The total force of the jacks, with a known total resistance and total force of movement is determined by the formula

\[
F_s = k_s \cdot F,
\]

where \( k_s \) - coefficient taking into account the work of the jacks when adjusting the position of the shield, \( k_s = 1.3 \ldots 1.5 \); \( F \) - force of movement of the shield, kN.

Statistical calculation of the shield produced for mountain and hydrostatic pressures, like rings in a ductile environment. The supporting structure is the shield body, which receives external loads, and the efforts of the shield jacks are transmitted to the blade and support rings. An optimal combination of external loads is taken for the calculation: the impact of only vertical rock pressure.

The calculated uniform distributed pressure on the shield is determined [10]

\[
q_p = \gamma \cdot \gamma_f \cdot H,
\]

where \( \gamma \) - rock density, kN / m\(^3\), taken as \( \gamma = 19.5 \text{ kN} / \text{m}^3 \); \( \gamma_f \) - load safety factor, \( \gamma_f = 1.1 \); \( H \) -calculated rock thickness above the shield, taking into account possible overload, \( H = 10 \ldots 12 \text{ m} \).

The design pressure on the supporting structure of the hull is determined with the condition of partial transfer of the load from the tail shell to the concrete ring [10]

\[
q_{hk} = \frac{q_p(l_{ik}+l_{is}+0.5l_{is})}{(l_{ik}+l_{is})},
\]
where $L_{lk}$ - length of the knife ring, m; $L_{ls}$ - length of the support ring, m; $L_{lt}$ - length of the tail section of the shield, m.

Statistical calculation determined the efforts (not taking into account the moments and normal forces) in sections of the shield. Further calculation determines the stresses in the sections with the highest value of the efforts.

The calculated moment and force in the shield sections are determined depending on the angle, with $\varphi = 90^{\circ}$ or $270^{\circ}$

$$M = -0.175 \cdot q_{hk} \cdot r_u^2;$$  \hspace{1cm} (11)

$$N = q_{hk} \cdot r_u,$$ \hspace{1cm} (12)

where $r_u$ - outer radius of the lining, $r_u = 2.42$ m.

Check the strength of the shield sections carried out by the formula [11]

$$\delta = \left( \frac{M}{W} \pm \frac{N}{A} \right) \leq |R_c|,$$ \hspace{1cm} (13)

where $\delta$ - voltage in the cross section, kN / m$^2$; $M$ - moment in the cross section of the tunnel shield, kN · m; $N$ - force in this section, kN; $W$ - section resistance moment, m$^3$; $A$ - cross-sectional area of the shield shell, m$^2$. $R_c$ - calculated resistance of the shield material to compression, $R_c = 21 \cdot 10^4$ MPa.

The moment of resistance of the cross section calculated by the formula [12]

$$W = \frac{\pi}{32} \cdot \left( D_s^2 - D_{si}^2 \right),$$ \hspace{1cm} (14)

where $D_s$ - outer diameter of the shield; $D_{si}$ - diameter of the shield is internal.

The cross-sectional area of the shield shell is determined [13]

$$A = \frac{\pi}{14} \cdot \left( D_s^2 - D_{si}^2 \right).$$ \hspace{1cm} (15)

If the condition is satisfied, (the pressure and the load on the shield do not exceed the allowable values) the construction can be considered operable, since the tunneling shield is able to withstand the arising workloads. This indicates the efficiency of the design of the tunneling shield when performing technological operations when drilling a well along a curved path.

The shield capacity required for the development of a breed depends on the type of executive body and the diameter of the shield, as well as on the resistance of the rock to destruction. The calculation of determining the power of the tunneling shield with a rotary working body.

The power spent on the development of the rock calculated by the formula [14]

$$N = \frac{2\pi M_f n_a}{\eta},$$ \hspace{1cm} (16)

where $M_f$ - torque on the shaft of the executive body, kN / m; $n_a$ - rotational speed of the actuator, s$^{-1}$; $\eta$ - efficiency of the drive, $\eta = 0.85 ... 0.9$.

The torque of the working body is determined by the formula [15]

$$M_f = 1.12 \cdot m \cdot z_k \cdot p_z \cdot \frac{D_c}{4},$$ \hspace{1cm} (17)

where, a multiplier of 1.12 takes into account additional resistances; $m$ is the number of incisors on one cutting line, $m = 8$; $z_k$ is the number of incisors simultaneously in contact with the face; $D_c$ - diameter of the cutting part of the working body.

The number of incisors is determined by the formula [16]

$$z_k = \frac{D_c}{2t_{opt}},$$ \hspace{1cm} (18)

where $t_{opt}$ - optimal cutting step, m ($t_{opt} = 0.048$ m, with $f_k = 1 ... 6$; $p_z$ - cutting force for the cutter, kN, with $f_k = 1 ... 6$)

$$p_z = 4 + 0.5f_k - (1.5 - 0.35f_k)^3.$$ \hspace{1cm} (19)

The frequency of rotation of the working body found by the formula [17,18]

$$n_a = \frac{V}{\pi D_s},$$ \hspace{1cm} (20)

where $V$ - circumferential cutting speed, $V = 15-25$ rpm; $D_s$ - outer diameter of the shield, m.
3. Conclusion

The methods of trenchless laying of communications are considered promising, since they require minimal opening of the earth's surface and ensure the safe construction of communications, both within the city and beyond, for example, under sea bays, rivers and mountain ranges.

The presented calculated dependences allow to determine the resistance to the movement of the shield in the process of drilling a well, static strength in order to establish the stresses in the shield structure and the required power required to destroy the rock in the course of the technological operation.

The proposed construction of the frame of the tunnel shield does not require the construction of a preliminary shaft and a platform for the installation of a drilling machine and makes it possible to combine in one working step the drilling of a well, the laying of a pipeline, welding and insulation works.

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