Improving the reliability of engineering collectors

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Abstract. The development of urban construction is closely linked with the active use of underground space, including the laying of reinforced concrete engineering collectors. The existing methods of protecting collectors from aggressive environmental influences do not provide the necessary reliability and safety. The article presents a new way of protecting engineering collectors using prefabricated reinforced concrete blocks with basalt-plastic lining. To prevent detachment of the lining from the concrete, the authors developed a method for fastening the lining to the inner surface of reinforced concrete blocks using basalt-plastic anchors. The article presents the results of calculating the required number of anchors per unit surface depending on the influence of various factors. The paper also presents the results of testing the design samples for water tightness and cleavage strength. The test results showed high efficiency of the proposed anchor basalt-plastic lining of reinforced concrete blocks for improving the reliability and geoecological safety of engineering collectors.

1. Introduction

In cities with a high building density, the combined laying of engineering communications in the collectors made of reinforced concrete blocks has become widespread.

Over time, aggressive substances acting on the internal surface of collectors (oil products, chlorides, sulfates, hydrogen sulphide, etc.), reduce their throughput, have a destructive effect on concrete, causing emergency depressurization. This leads to contamination of underground and surface waters, soil and atmosphere. Methods of secondary protection of reinforced concrete collectors using different types of waterproofing materials (coatings based on organic and inorganic materials, steel sheets, etc.) are not effective enough.

At present, the development of new methods for the reliable protection of collectors becomes particularly urgent.

One of such protection methods is the use of prefabricated blocks with basalt-plastic lining [1-4]. The authors developed composition of the lining after studying the structure and properties of its elements, as well as tests for crack resistance, water resistance, strength, corrosion resistance, etc. Thus, the composition of the lining is a special multilayer covering (Figure1) consisting of nanomodified thermosetting resins, chopped basalt fibers, basalt fabric and metal reinforcing elements (Table 1) [5]. It is attached to the inner side of reinforced concrete blocks to protect them from possible mechanical, thermal, physical and chemical damage.
Table 1. Composition of basalt-plastic lining.

| Material          | Mass (%) |
|-------------------|----------|
| Thermosetting resin | 70       |
| Basalt fibers     | 15       |
| Basalt fabric     | 15       |

To prevent detachment of the lining from the concrete surface, the authors developed a method for fastening the lining to the inner surface of reinforced concrete blocks using basalt-plastic anchors. Calculations of anchors were carried out depending on various factors acting on the structure [6-9].

Evaluation of the reliability of lining fastening was carried out in accordance with the methods set out in GOST 28574-2014 [10].

2. The results of investigation

2.1. Calculation of anchors transmitting power load between basalt-plastic lining and reinforced concrete.

The authors suggested using lining fastening with basalt-plastic anchors, vertically protruding from the internal line and embedded in reinforced concrete.

Basalt-plastic lining is fastened on the inner side of reinforced concrete blocks. It is installed during technological process of blocks production before concreting and mounting of steel reinforcement.

To calculate the anchors that provide power transmission between basalt-plastic lining and reinforced concrete, various design load cases were considered [11-15]:

Figure 1. Basalt-plastic lining.
• Using of a vacuum erector when removing a block from a mold. In this case fastening of lining anchors should be calculated with regard to the weight of the reinforced concrete block.
• Using of a clamshell erector in a tunneling machine. In this case the clamshell erector is installed immediately in the reinforced concrete block and fixed by the erector dowel.
• The water pressure in the tunnel is not taken into account when calculating the anchors, since this load presses the basalt-plastic liner against reinforced concrete and strengthens their connection with each other.
• The groundwater pressure on the outside of the tunnel must be taken into account additionally when calculating the lining.
• Elimination of the danger of cavities. The cavities do not have a direct negative impact on the transfer of load between the basalt-plastic lining and reinforced concrete, since the transfer of the load occurs through the rear attachment. The water pressure in the pores due to pressure from the outside to the tunnel can, however, cause flaking [16, 17].

Calculation of the fastening of basalt-plastic lining for reinforced concrete blocks was carried out on the basis of the conditions presented in Table 2.

Table 2. Boundary conditions for calculation of basalt-plastic lining.

| Inner diameter of the tunnel (m) | 2.750 |
|----------------------------------|-------|
| Width of a ring (m)              | 1.0   |
| Number of the rings              | 6     |
| Fastening of segment             | vacuum erector and clamshell erector |
| Weight of the lining (kg)        | 10    |
| Inner water pressure (kN)        | 0 (natural course) |
| Pressure of ground water (kN)    | 150   |
| Design load (kN)                 | 150   |
| Using of vacuum erector          | is absent |
| Using of clamshell erector       | is absent in the tunnelling machine |

Using the data presented in Table 2, the geometric dimensions of the basalt-plastic lining is determined by the formula (1):

\[ L_l = \frac{d_t \times \pi}{n} = \frac{2.75 \times 3.14}{6} = 1.44 \text{ m} \]  

\( L_l \) – length of the lining, m  
\( d_t \) – inner diameter of the tunnel, m  
\( n \) – number of rings.

Considering that the width of the ring is 1.0 m, the area of basalt-plastic lining is determined by the formula (2):

\[ A_l = L_l \times b_l = 1.44 \times 1.0 = 1.44 \text{ m}^2 \]  

\( A_l \) – area of the basalt-plastic lining, m²  
\( b_l \) – width of the lining, m.

Based on the geometric parameters of the basalt-plastic lining and the technology of producing reinforced concrete blocks with lining (the anchors do not reach the edges of the reinforced concrete block for 5 cm on each side for mounting the embedded parts and the reinforcing cage), the length of one anchor is 0.9 m.
The initial data for calculating the number of basalt-plastic anchors are presented in Table. 3.

**Table 3. Initial data for calculation of basalt-plastic anchor.**

| Design load (kN)          | 150          |
|---------------------------|--------------|
| Safety factor             | 2            |
| Bearing capacity of 1 rm of a basalt-plastic anchor (kN/rm) | 54           |
| Area of basalt-plastic lining (m²) | 1.44         |
| Length of one basalt-plastic anchor, m | 0.9         |

The required total length of the basalt-plastic anchor is determined by the formula (3):

\[ L_{an} = \frac{F_d \times \gamma}{Q_{an}} = \frac{150 \times 2}{54} = 5.6 \text{ rm/m}^2 \]  

(3)

$L_{an}$ – total length of the basalt-plastic anchor rm/m²;  
$F_d$ – design load, kN;  
$\gamma$ – safety factor;  
$Q_{an}$ – bearing capacity of 1 rm of a basalt-plastic anchor, kN/rm

The required number of basalt-plastic anchors is determined by the formula (4):

\[ n_{an} = \frac{A_l \times L_{an}}{l_{an}} = \frac{1.44 \times 5.6}{0.9} = 8.96 \text{ units}, \]  

(4)

$n_{an}$ – required number of basalt-plastic anchors, units  
$A_l$ – area of the basalt-plastic lining, m²  
$L_{an}$ – total length of the basalt-plastic anchor rm/m²;  
$l_{an}$ – length of one basalt-plastic anchor, m.

Thus, 9 basalt-plastic anchors (0.9 m long) are required on each inner surface of the lining. Anchors may additionally have openings (Figure 2), which will provide additional fastening strength with reinforced concrete.

**Figure 2. Basalt-plastic anchors with openings.**
According to the results of calculations, an experimental lining block was made for carrying out laboratory tests. This block had the proposed construction of fastening the basalt-plastic lining to the concrete base with the help of basalt-plastic anchors (Figures 3, 4).

Figure 3. Basalt-plastic lining with anchors in casing form.

Figure 4. Basalt-plastic lining with anchors in casing form with mounted reinforce frame.
2.2. Laboratory tests of cleavage strength of basalt-plastic lining from reinforcement concrete base

For comparative analysis, lab tests were carried out on reinforced concrete blocks with the proposed lining and without it (in accordance with GOST 28574-2014). In order to increase the adhesion of basalt-plastic with reinforced concrete, sand of various sizes (coarse, average and fine fractions) was applied to the inner surface of the basalt-plastic lining during molding [18, 19].

The results of laboratory tests of cleavage strength of the basalt-plastic lining from the reinforced concrete base with the use of basalt-plastic anchors (Figures 5-8) showed that breakdown areas of samples with basalt-plastic lining were mainly in concrete. At the same time, the adhesion of the basalt-plastic lining to the concrete was not disturbed. When using coarse sand, the fracture area was 100%, the average fraction – 70%, and the fine fraction – 40%. In the peel test, a load of 3.04; 3.06; 3.67 MPa respectively was applied (the minimum permissible load is 1 MPa).

The results of the same tests of cleavage strength of the basalt-plastic lining without anchors using sand the same fractions gave the results 0.94; 098; 1.08 MPa accordingly.

On the basis of the obtained results, it can be concluded that the use of basalt-plastic anchors increases cleavage strength of the lining from the reinforced concrete base by 3 times in comparison with constructions without basalt-plastic anchors and normative values.

Permeability tests showed that the proposed lining is completely impermeable to water and aggressive substances.

2.3. Full-scale tests of the developed structure

Full-scale tests of the developed basalt-plastic lining were carried out during the erection of the engineering collector «Novo-Kuzminki» (in accordance with SP 129.13330.2011 [20]).

The construction site was located in the South-Eastern Administrative District of Moscow, in a complex urban development. For the experimental tunnelling, 2 rings (12 blocks of lining) were made with basalt-plastic lining with anchors. During the hydraulic testing of the experimental site, the water leakage decreased by 5 times, compared to the normative ones (0.38 <1.97L), which indicates a decrease in the risk of soil contamination due to a decrease in the number of emergency depressurizations of engineering collectors.
3. Conclusion
The results of the tests showed the high efficiency of using basalt-plastic anchors for fixing the lining to reinforced concrete blocks to improve the reliability and geo-ecological safety of engineering collectors. The use of basalt-plastic anchors increased the cleavage strength of the liner from the reinforced concrete base by 3 times in comparison with the constructions without basalt-plastic anchors and normative values. Hydraulic test of experimental site showed decrease of water leakages in 5 times in comparison with the regulations, which indicated a reduction of soil contamination risk by reducing the number of emergency depressurization engineering collectors.

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