Filtering polymer material for wall drainage

Olga Lyapidevskaya

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia

E-mail: olga.lyapidevskaya@inbox.ru

Abstract. The article deals with the ensuring reliable protection of underground buildings and structures from groundwater influence. The analysis of existing methods and materials used in wall drainage systems is carried out. In order to improve the quality of construction and operation of underground structures, filtering drainage slabs made of polystyrene foam are proposed. To develop the design of slabs with longitudinal holes that increase their water permeability, the method of electro hydrodynamic analogies was used. Deformations of filtering slabs with holes with a diameter of 4 cm under the action of compressive loads exerted by backfill soil were investigated. Dependence of the compressive strength and water permeability of filtering slabs upon short-term (compressibility 10%) and long-term (compressibility 2%) loads is presented. Based on the results of the experiment, it is found that the obtained material has high filtration characteristics with sufficient strength and can be recommended for the protection of underground structures with a depth of up to 10 m.

1. Introduction

The traditional methods of protecting underground structures from groundwater include installation of multilayer roll waterproofing in combination with sand and gravel filling. However, these methods do not meet the necessary requirements due to the high complexity and low quality of drainage. In this regard, the basements of residential and industrial buildings are often subjected to flooding. This deranges the normal heat and humidity operating conditions and leads to the destruction of concrete structures [1-10].

In recent years, wall drainage made of single-layer and multi-layer plastic membranes with rounded protrusions has become widespread. They have high mechanical strength, resistance to various chemically aggressive substances, are able to withstand the load from the backfill soil up to 0.05 MPa, and are convenient for transportation. Plastic membranes have some advantages over traditional waterproofing systems, but they are quite rigid, which makes it difficult to overlap seams, and their connection requires the use of special mastics. In addition, they are not always effective and have a high cost [11-15].

In order to improve the quality of construction and operation of underground structures, methods of protection against groundwater are being actively developed using wall drainages in the form of prefabricated elements made of filtrating slabs and pipe filters. In this case, there is no need to arrange sand and gravel fillings, pressure (protective) walls, and in some cases roll waterproofing (figure 1).
Filtering concrete slabs have been developed as prefabricated drainage elements. The porous structure of the material was achieved by selecting a composition in which the cement mortar only enveloped the aggregate grains (expanded clay, gravel) without filling the space between them. Having sufficient water permeability (50-100 m/day) and high compressive strength (2.5-10 MPa), concrete slabs have several disadvantages. They are too heavy, which complicates their transportation and installation; in addition, they can only be used under non-aggressive groundwater conditions due to low corrosion resistance [16-18].

Thus, the analysis of the materials used for the installation of waterproofing systems indicates the need to develop an effective drainage material to protect the underground parts of buildings and structures devoid of the above disadvantages.

2. Materials and theoretical analysis
In order to create a durable construction of wall drainage with high water permeability and resistance to aggressive groundwater, we attempted to develop a filtering material obtained by sintering polystyrene foam granules using a special technology. Slabs made of filtering polystyrene foam, having high coefficient of filtration, sufficient strength and chemical resistance can be used as wall drainage of buildings and structures.

Optimal technological parameters for the production of filtering polystyrene foam have been worked out. The grain-size composition and heat-humidity mode of processing the material is selected in such a way that the polystyrene foam granules during molding are sintering between each other only in contact points, forming an open intergranular (filtering) porosity.

Covering the walls of building basements and underground structures with drainage slabs will not only protect them from groundwater, but also improve the thermal and moisture properties of the walls. It is recommended to use drainage slabs with a size of 1000×500×100 mm. However, in urban conditions with a layered structure of the backfill soil, local concentrated water flow to the wall

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**Figure 1.** The structure of the underground part of the building with filter slabs.
1 – wall; 2 – waterproofing material; 3 – floor covering; 4 – cement covering; 5 – waterproofing coating; 6 – foundation plate; 7 – drainage slabs; 8 – separation film; 9 – concrete bed; 10 – soil backfill; 11 – drainage pipe; 12 – gravel filling; 13 – gravel
drainage is possible. In these conditions, to prevent water intrusion to the wall of the protected structure, the filter thickness should be significantly increased. This can be avoided by arranging longitudinal holes in the drainage slabs. The optimal distance between the holes, at which the slabs completely intercept the water flow, as well as the nature of the distribution of the moisture flow across the slabs were determined by the method of electro hydrodynamic analogies (EHDA) on electrically conductive paper [19].

3. Methods
To simulate the filtration, we used hydraulic and electrical analogies implemented on solid models when comparing the basic laws of the motion of the filtration flow – Darcy’s law (1) and electric current – Ohm’s law (2):

\[ Q = -k \omega \frac{dH}{dl} \]  
\[ I = -c \omega_M \frac{dU}{dl_M} \]

To perform the similarity, the corresponding characteristics of the processes should be interconnected by scale factors (3):

\[ a_Q I = a_k a_l^2 a_M \frac{a_H dU}{a_l d l_M} \]

In this case, the following condition should be met: \( a_Q = a_k = a_l = a_H \), \( a_Q, a_k, a_M, a_l \) – scale factors; \( a_l = l/l_M \) – linear scale factor; \( a_M = \omega^2_M \); \( a_k = k/k' \); \( a_H = \Delta H/\Delta U \); \( a_Q = Q/I \) – scale factors of permeability, pressure, and flow rate, respectively;

\( k \) – filtration coefficient;
\( c \) – specific conductivity;
\( \rho = 1/c \) – resistivity of the material model;
\( \Delta H \) – change in pressure;
\( I \) – current strength; \( U \) – electric potential;

The simulation was carried out on a scale \( a_l = 1:1 \). The thickness of the drainage slab \( l = l_M \) – 10 cm. The hole diameter – 4 cm. The holes were modeled with metal cylinders (figure 2).

The results of modeling water filtration in the slab are presented in table 1 and figure 3. Analysis of the simulation results shows that the vertical holes in the drainage slab, located at 6 cm or less,
completely intercept the flow of moisture going to the back of the slab (to the structure). Thus, the recommended geometric parameters of the slabs satisfy the drainage requirements.

**Figure 3.** Simulation of the drainage slab operation made of filtering polystyrene by the EHDA method. The distance between the centers of the vertical holes (mm):

a – 50; b – 100; c – 140; 1 – equipotentials (lines of equal potentials); 2 – current lines.

**Table 1.** The results of simulation of water filtration in a slab.

| The distance between the holes (mm) | The distance between the centers of the holes (mm) | The length of the filtration area going to the back of the slab (mm) | The volume of filtration flow passing to the wall of the structure (%) |
|-------------------------------------|-----------------------------------------------|-------------------------------------------------|---------------------------------------------------------------|
| 10                                 | 50                                           | 0                                               | 0                                                             |
| 60                                 | 100                                          | 0                                               | 0                                                             |
| 100                                | 140                                          | 25                                              | 21,7                                                          |

4. Results

The research task was to determine the deformations of the filtering slabs with holes 4 cm in diameter under the action of compressive loads exerted by the backfill soil. The ground pressure increases with the depth of the underground structure. At the same time, the thickness and drainage capacity of the drainage slabs may change. The calculation of external loads from the lateral pressure of the soil on the wall drainage made of filtering polystyrene slabs was carried out according to the formula (4) [20]:

\[
G = \gamma h t g^2 \left( 45^\circ - \frac{\varphi}{2} \right)
\]  

(4)
FORM-2020
IOP Conf. Series: Materials Science and Engineering 869 (2020) 032017 doi:10.1088/1757-899X/869/3/032017

\( G \) – lateral soil pressure, MPa;
\( \gamma \) – soil density, \( \gamma = 1800 \text{ kg/m}^3 \);
\( h \) – depth, m;
\( \varphi \) – angle of internal friction of the soil; accepted for sand and sandy loam \( \varphi = 27^\circ \); for loam \( \varphi = 24^\circ \); for clays \(-\varphi = 16^\circ \).

Table 2 shows data on the permissible lateral pressure loads of different types of soil on the wall drainage, depending on the depth of the foundation.

| Type of soil     | Depth of the foundation (m) |
|------------------|-----------------------------|
|                  | 3  | 5  | 7  | 9  | 10 | 12 |
| Sand             | 0.013 | 0.022 | 0.030 | 0.038 | 0.043 | 0.051 |
| Sandy loam       | 0.020 | 0.033 | 0.046 | 0.060 | 0.066 | 0.080 |
| Loam             | 0.023 | 0.040 | 0.053 | 0.068 | 0.076 | 0.091 |
| Clay             | 0.031 | 0.051 | 0.071 | 0.092 | 0.102 | 0.123 |

The strength of filtering slabs with holes of 4 cm was determined under the action of short-term and long-term loads. The results of the compressive strength of the filtering slabs under short-term (compressibility 10%) and long-term (compressibility 2%) loads depending on the material density are presented in figure 4.

![Figure 4](image.png)

**Figure 4.** The dependence of the compressive strength under short-term and long-term loads

1 - short-term load, compressibility 10%; 2 - long-term load, compressibility 2%

As follows from figure 4, the strength at 10% compression of filtering polystyrene foam samples with holes with a diameter of 4 cm, depending on the density of the material, is from 0.06 to 0.17 MPa, which corresponds to a laying depth of slabs of underground structures up to 10 m.

The analysis of the compressive strength results of the drainage slab was carried out in the basis of the following condition (5):

\[ R \geq G \cdot k \]  

\( R \) – strength at 10% compression, MPa;
\( G \) – lateral ground pressure, MPa;
\( k \) – safety factor of 1.5.

Studies of the filtration characteristics of filtering polystyrene foam, depending on the degree of compression, were carried out. The data in table 3 show that the water permeability of slabs with holes...
with a diameter of 4 cm at 2% and 10% compression of the material is quite high, the filtration coefficient at 2% compression is from 1040 to 274 m/day, and at 10% compression is from 750 to 170 m/day, which slightly affects their drainage ability.

Table 3. The water permeability of filtering slabs depending on the degree of compression and density of the material.

| Density (kg/m³) | Filtration coefficient (m/day) at compression (%) |
|----------------|---------------------------------------------------|
| 14  | 1500  | 1040  | 750  |
| 16  | 1120  | 780   | 638  |
| 18  | 990   | 690   | 520  |
| 20  | 809   | 635   | 470  |
| 24  | 629   | 410   | 300  |
| 26  | 390   | 300   | 195  |
| 28  | 320   | 274   | 170  |

5. Conclusion

The following conclusions can be drawn from the analysis of the obtained results.

Drainage slabs made of filtering polystyrene with holes with a diameter of 4 cm are effective when the depth of underground structures is up to 10 m, which corresponds to most residential and industrial buildings. For deeper installation of slabs, their density should be higher, but in this case their filtration characteristics will be lower. Thus, the use of lightweight, large-sized, resistant to aggressive groundwater slabs made of filtering polystyrene foam in the construction of wall drainage will improve the quality of protection of underground structures, abandon fillings from scarce granite rubble and classified sand, reduce construction costs and abridge the labor expenditures.

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