Assessment of maintainability and resistance to external influences of PVC waterproofing membrane systems

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Abstract. Recently, waterproofing systems made of PVC membranes, used in the construction of high-rise buildings with a developed underground part, have gained great popularity. Due to the considerable depth and magnitude of static loads at the foundation level, the complete replacement of such waterproofing with standard methods in case of its damage is practically impossible. To avoid this situation, a multi-layer PVC waterproofing membrane system with a geotextile middle layer was created. To repair such a system it is supposed to inject a polymer composition into it through special tubes, which after curing restores the waterproofness of the membranes. The article presents the results of an experimental assessment of the maintainability of the described waterproofing system. It was proved that the injection of the repair composition into the middle geotextile layer is possible even with external static pressure on the membranes of 146 t/m². At the same time, the high resistance of PVC membranes to the long-term action of a significant static load and repair composition was found, and the durability of a waterproofing system, predicted from the point of the thermal-fluctuation theory of the destruction of solids, under operating conditions for shear was about 50 years.

1. Introduction

Waterproofing plays an important role in ensuring the performance of supporting and enclosing structures. Its violation often leads to the decrease in the heat-shielding qualities of fences and in some cases to a partial destruction of the supporting structures [1]. Nowadays bitumen is replaced by more technological waterproof materials in the form of polymeric PVC membranes, which make a protective system with the function of detecting leakages and the possibility of repairing waterproofing during operation (application for utility model RU No. 2019102460, 29.01.2019). However, due to the insignificant experience of using such systems in foundations, roofs and other elements of building constructions (for example, waterproofing of sewage treatment plants or septic tanks of livestock breeding complexes, etc.), a lot of questions arise, many of which are considered in scientific works, including foreign ones [2-7].

Recently, PVC waterproofing membrane systems have been used in the construction of high-rise buildings, based on the foundation arranged by the method of "wall in the ground". When the reinforced concrete gets the wall strength and the pit is developed, the slab foundation, which requires waterproofing located between the base soil and the slab, is made inside the contour at the required level. Thus, PVC membranes, located under the slab foundation, are subjected to prolonged exposure to significant static load and the influence of groundwater [8-10]. The work devoted to the study of
waterproofing with an internal safety drainage layer of geotextiles [11] notes that in the contiguity zone of floors and the foundation plate (depending on the adopted construction technology), the shear pressure can reach 146 t/m². At the same time, manufacturers of geosynthetic canvas guarantee the preservation of its drainage properties only up to a pressure of 40 t/m² [12,13].

Unfortunately, in the pursuit of profit, unscrupulous manufacturers of waterproofing systems, often not having the results of qualitative field and laboratory tests, issue false long-term guarantees for their products. Ultimately, this leads to disruption of normal operating conditions not only for individual structures, but also for buildings as a whole. In addition, the repair of such systems involves the implementation of a large amount of work associated with the replacement of waterproofing material, which is quite expensive and time consuming.

Thus, the issues of maintainability, reliability and possibility of correctly predicting the service life of waterproofing systems made of PVC membranes at their location in the structures of underground constructions remain relevant. In this regard, the purpose of this work is to assess the maintainability of waterproofing cards, which is a model of a vacuum waterproofing system consisting of two layers of PVC membranes with a layer of geotextiles, as well as a comprehensive study of the physico-mechanical indicators of PVC membranes after external pressure and contact with repair composition.

2. Materials and Methods
For testing, we made models of waterproofing cards of various configurations, which are presented as a model of a vacuum waterproofing system consisting of two layers of unreinforced PVC membrane PLASTFOIL® Geo, 1.5 and 2.0 mm thick with a geotextile interlayer of different density (150, 300 and 500 g/m²), connected along the perimeter by means of hot air welding. In the top layer of the PVC membrane of each waterproofing card, a fitting was installed to supply the repair injection compound.

The maintainability of the resulting waterproofing system was evaluated by the possibility of injecting repair composition (gel acrylate) into the models of waterproofing cards under external pressure. The prepared models were alternately placed under a press and squeezed for 2 hours under a pressure of 146 t/m² (1.46 MPa), after which a vacuum system was connected to the control injection piece. In the presence of air permeability of the system, the injection repair composition with a viscosity of 2-3 MPa·s was added under a pressure of 30 bar.

After complete curing of the gel acrylate, the models of waterproofing cards were opened and the samples of PVC membranes were prepared for mechanical tests in accordance with GOST (tensile, tear, elongation, strength of the weld). The tests were carried out on a Testometric M350-5AT tensile testing machine.
The most dangerous type of stress, leading to the destruction of membranes and waterproofing systems, is shear. It occurs as a result of short-term or long-term point action on the membranes of the cores of reinforcement cages while installing supporting structures. In this regard, the work also evaluated the resistance to shear PVC membranes exposed to external pressure and repair composition.

For short-term and long-term tests of PVC membranes, samples of a strip of 200x20 mm in size of various thickness were made. Three-layer samples cut from the models of waterproofing cards with a geotextile layer with density of 150, 300 and 500 g/m² were also tested. The samples were made of two types: without impact and after exposure to the load and contact with the repair composition.

Based on the results obtained by the authors earlier and presented in [14–16], the durability of PVC membranes was estimated according to the thermal-fluctuation theory of the strength of solids [17,18]. The relationship of time to destruction $\tau$ with voltage $\sigma$ and temperature $T$ is described by equation (1):

$$
\tau = \tau_m \exp \left[ \frac{U_0 - \gamma \cdot \sigma \cdot \left( 1 - \frac{T}{T_m} \right)}{R \cdot T} \right]
$$

where $\tau_m$ is the minimum durability (the oscillation period of kinetic units: atoms, molecules, segments), s; $U_0$ is the maximum activation energy of the destruction process, kJ/mol; $\gamma$ - a structural-mechanical constant, kJ/(mol•MPa); $T_m$ is the limiting temperature for the solid existence (decomposition temperature), K; R is a universal gas constant, kJ/(mol•K); $\tau$ is time to destruction (strength durability), s; $\sigma$ is stress, MPa; $T$ is temperature, K.

The universal nature of the time dependence of the strength, allowing to assess the durability of PVC membranes when they are working on the shear, has the following form (2):

$$
\sigma = \beta \lg \left( \frac{a}{\tau} \right); \tau = Ae^{-\beta \sigma}
$$

where $a$ and $\beta$ are constant coefficients which determine the dependence of durability ($\tau$) on stress ($\sigma$) at a constant test temperature.

With fixed stresses $\sigma$ and constant temperature, six samples were tested under the same conditions and the time to destruction $\lg \tau$ was determined. For each type of samples, the dependency graphs of the time to destruction on the stress were developed in coordinates $\lg \tau - \sigma$.

3. Results and Discussion

The vacuuming of waterproofing cards with an internal geotextile layer under load showed that air permeability is maintained even at a press pressure of 146 t/m² (1.432 MPa). The injection at this pressure was also possible. At the same time, the repair composition filled the entire internal space, thereby restoring the integrity of the card and its waterproofing properties. The average values of the controlled physico-mechanical parameters of the studied samples, as well as their comparison with the values reflected in TU 23.99.12.110-012-54349294-2016, are presented in table 1.

According to the obtained results, it was established that the impact of the load and repair composition does not have a significant effect on the strength and deformation characteristics of the membrane. Characteristic changes are minor and comply with regulatory requirements.

The nature of the strength change during the shear depending on the type of samples and the type of impact on the material are presented in figure 2.

According to the findings (Figure 2a), the short-term shear strength of membranes with a thickness of 2.0 mm is slightly reduced (to 10%), and in the case of membranes with a thickness of 1.5 mm it even increases by 7% due to orientational phenomena in the polymer structure arising from its compaction under the influence of large pressure collapse. The repair composition does not affect the strength properties of the membrane, since this waterproofing material has a high chemical resistance [19,20].

Figure 2b shows the change in strength when cutting three-layer samples with different thickness and density of geotextiles. The significant decrease in strength compared with single-layer samples is
explained by the fact that the force applied to the sample is divided by the entire thickness of the structure, whereas in fact the strength of the sample is determined by the shear strength of the geotextile. The repair composition (gel-acrylate) reduces the ability of geotextiles to resist shear, since the polymer impregnates the fibers, making the material more dense and rigid, and changing the mechanism of its destruction to brittle. The strength is most severely reduced in samples with a geotextile density of 300 and 500 g/m² - more than 20%, whereas for samples with a geotextile density of 150 g/m², the strength value remains almost unchanged (less than 5%). Therefore, in the construction of waterproofing cards, it is advisable to use geotextiles with a density of 150 g/m² as an internal drainage layer.

### Table 1. Changes in the physico-mechanical parameters of PVC membranes after mechanical and chemical effects, their compliance with standard values.

| Controlled parameter | Parameter value in accordance with GOST, no less than |
|----------------------|-----------------------------------------------------|
| Membrane thickness, mm | 1,5 | 2,0 | 1,5 | 2,0 |
| Durability at stretching (MPa), GOST 31899-2011, Method B | 20,2 | 19,3 | 18,9 | 19,1 | 17 |
| Elongation at maximum load (%), GOST 31899-2011, Method A | 373 | 426 | 390 | 442 | 300 |
| Tear resistance (N), GOST R 56583-2015 | 164 | 247 | 150 | 210 | 150 |
| Tear strength of the weld (H/50mm), GOST R 56584-2015 | - | - | 438 | - | 300 |
| Tensile strength of the weld (H/50mm), GOST R 56911-2016 | - | - | 1032 | - | 600 |

**Figure 2.** Dependency of short-term shear strength on the type of impact for samples: a) PVC membrane of 1.5 and 2 mm thickness; b) three-layer waterproofing cards with a geotextile density of 150, 300 and 500 g/m².

The evaluation of PVC membranes durability with a long-term shear from the point of the thermal-fluctuation theory of the strength of solids is presented in figure 3.
Figure 3. Dependency of time to destruction on stress at constant temperature for samples: a) PVC membrane of 1.5 mm thickness; b) PVC membrane of 2 mm thickness; c) three-layer waterproofing cards with a geotextile density of 150 g/m2.

Figure 3a, b present that PVC membranes show a slight decrease in long-term strength after exposure of the material to external load and contact with the repair composition. The change in the inclination angle of the lines in both cases after external influences indicates structural changes in the material as a result of the polymer compaction. At the same time PVC membrane fully retains its operational properties.

Figure 3c shows that there is a more significant reduction in the long-term strength of a three-layer sample with a geotextile layer of 150 g/m² density after exposure to pressure of 146 g/m² and contact with the repair composition. In this case, there is also a sharp change in the inclination angle of the straight line, which is caused by the change in the nature of the internal drainage layer (geotextile) destruction as a result of its curing due to the polymerization of the repair composition.

Thus, the durability of PVC membranes, calculated by the equation 2, when working on a shear, taking into account external mechanical and chemical (repair composition) effects, is about 50 years.

4. Conclusion
During the work, an assessment of the maintainability of waterproofing cards, which are presented as a model of a vacuum waterproofing system consisting of two layers of a PVC membrane with a geotextile layer, was made. The results indicate that this structure allows to control any waterproofing area during the facility construction and operation, and, in the case of local damage, to perform repairs even with significant external pressure, without dismantling and damage to supporting structures.
A comprehensive study of the physico-mechanical properties of PVC membranes showed their high resistance to mechanical and chemical effects. The change in the strength and deformation properties of membranes after exposure to external pressure and repair composition in most cases is insignificant (up to 10%). Moreover, all indicators fully meet the requirements of TU 23.99.12.110-012-54349294-2016.

The dependencies of the time to destruction on the stress obtained during long-term mechanical tests indicated that the polymer structure changed under the influence of an external load and made it possible to calculate the approximate durability of PVC membranes when working on the shear, taking into account external mechanical and chemical effects.

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