Using foam polyurethane sealers for strengthening of soils of a road bed of transport constructions

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Abstract. The article presents an overview of the methods of producing alternative building materials by strengthening soils with organic binders based on synthetic resins. Their use in road construction would meet the needs of construction organizations in high-quality building materials and ensure reliable operation of soil masses of subgrade road transport structures throughout estimated service life. The authors proposed a new, alternative method for soil stabilization using urethane foam sealants, which have proven themselves in civil engineering in the form of mounting foams. The paper describes a method for strengthening soil with sealants, its labor production technology, properties and physical and mechanical characteristics. The results of the trial experience of soil strengthening with polyurethane foam sealant are described and conclusions are made based on the work.

Keywords: road, subgrade, soil strengthening, pavement, organic binder, polyurethane foam sealant, mounting foam.

1. Introduction
During the construction of roads, in most cases, cohesive soils act as soils of natural bases. This is due to the fact that the resource of local building materials suitable for the construction of the subgrade and the working layer often cannot fully meet the needs of builders. In order to reduce the cost of construction, the subgrade is built from local silty and clay soils.

During the life cycle of the transport structure, the subgrade is exposed to external climatic influences. The factors affecting the subgrade are diverse and depend on the time of year. The main factors affecting the efficiency of the pavement are waterlogging and freezing of the soil of the subgrade. The experience of operating transport facilities shows that the service life of pavement on roads passing through waterlogged areas is much less, and the main destruction occurs at the stages of excessive waterlogging of the subgrade.

Waterlogging of cohesive soils of the subgrade leads to a decrease in their strength more than twice, thereby reducing the overall strength of pavement by more than 25 %. The decrease in soil strength with increasing humidity is clearly visible on the graph in Fig. 1 [1]. In regions with persistently low temperature in winter, the maximum decrease in the strength of the pavement occurs in spring, when the thawing of frozen soils goes beyond the additional base layer into the working layer of the subgrade [2].

With this circumstance, the question of how to build a subgrade that can withstand several overhaul cycles and at the same time preserve the strength characteristics sufficient for the safe operation of the structure is even more acute.
The solution to the above problem should be sought in achieving such a condition of the subgrade that its humidity during the year does not exceed the optimum humidity. Since the strength properties of soils, in this state, almost reach a maximum [4].

Currently, in order to solve this problem, reinforcement of soil subgrade is carried out by mechanical, physical or chemical methods. However, based on the results of previous studies [5], we can say that the known methods have a large number of limitations and disadvantages. In particular, it lies in the properties of soils that are not suitable for strengthening. In the Russian Federation regulatory documents [6–8] limit the suitability of the soil for reinforcement in the following indicators: the number of plasticity, grain composition, content of humus particles, the degree of salinity, humidity, etc. Therefore, an even more urgent question arises about the search for scientific solutions to extend the life cycle of the subgrade under any soil conditions.

The method of strengthening the soil of the subgrade with polyurethane foam sealants is based on the use of polyurethane foam that has positively proven in civil engineering (hereinafter – Sealant). Polyurethane foam sealant is a thermosetting polymer belonging to the condensation type, consisting of isocyanate, polyol and auxiliary substances (catalysts, blowing agents, etc.).

Mounting foam has a number of irreplaceable properties in construction, due to which it can provide the necessary quality of soil reinforcement of any types. These properties include:

- speed of strengthening process (full hardening of foam maximum 24 hours, standard from 4 to 8 hours);
- high adhesion of sealant with soil particles (the adhesion of foam higher to wet surfaces, which in the conditions of strengthening of water-saturated soils is undoubtedly a plus);
- increase in the volume of the introduced sealant (up to 20 times). Due to a significant increase in volume, the foam penetrates into the micropores of the soil, absorbing the necessary for the formation of its own structure and displacing excess moisture;
- drainage of weak water-saturated soils (the cross-linking mechanism of one-component polyurethane sealants is carried out due to the interaction of isocyanate groups with moisture) [9];
- formation of a layer with a low coefficient of thermal conductivity (thermal conductivity of the foam 0.003 W/mK).

A method of strengthening the soil Sealants can be used on the contact systems «pavement – weak foundation» (Fig. 2, a), «pavement – subgrade» (Fig. 2, b), and in the middle part of the arranged subgrade (Fig. 2). Due to its properties, the Sealant can not only increase the water/frost resistance and strength characteristics of the soil, but also provide the formation of a capillary and vapor

![Figure 1. Dynamics of soil strength](image-url)
impermeable insulating layer, which is especially important in the second road-climatic zone, when dealing with the formation of the gleyed soil subgrade [5].

![Figure 2. The device of the pavement of the road with reinforced soil according to the system: a) «Pavement – weak foundation»; b) «Pavement – subgrade»; c) In the middle part of the arranged subgrade; (1) – the accompanying drainage removed from the soil reinforcement zone; (2) – additional (frost protection) layer; (3) – the working layer of the subgrade, reinforced with a sealant; (4) – subgrade of the local silty or clay soils; (5) – leveling sand layer; (6) – the spike of the working body for the supply of Sealant; b(7) – Capillary-breaking layer reinforced with mounting foam.](image)

In Russia and a number of foreign countries studies are conducted to strengthen the soil bases and coatings of roads with cold-cured synthetic resins [10, 11]. As binders, additives are used: urea-formaldehyde resins of various compositions, furfuralaniline resins; resorcinol-formaldehyde resins; acrylic compounds; lignosulfate and lignoprotenic compounds; organosilicon and other resins [12].

In the course of the research, based on the results obtained, the following conclusions were made: additives of synthetic resins provide the formation of a strong and hydrophobic structure, water and frost resistance of the strengthened soil; samples obtained by strengthening with synthetic resins from loamy soils withstood up to 50 cycles of freezing and thawing, from sandy soil – 115 cycles; light loamy and clay soils with moisture equal to the lower yield stress, acquire water resistance and considerable strength; condensation polymers are less sensitive to soil impurities and air oxygen than polymerization polymers, which contributes to more stable curing [12].

Also, experiments on soil strengthening with resorcinol-formaldehyde resins showed the ability of the binder to bind water in an amount exceeding the mass of gummers 2–2.5 times. This allowed researchers to conclude that it is advisable to use it to strengthen waterlogged soils [12].
Currently, the research conducted in the field of application of polyurethane binders in road construction is mainly aimed at strengthening slopes, recesses, bulk structures, cones of bridges and overpasses, the surface of which is strengthened by rubble or gravel, in order to protect them from external environmental factors [13–15].

In preparation for the experimental part of the research, on the basis of the Department of «Roads, bridges and tunnels» of the St. Petersburg state University of Architecture and Civil Engineering, a trial experiment was prepared and conducted to strengthen the cohesive soil with a sealant. As a binder was chosen single-component, all-season, polyurethane foam. The experiment showed that when a binder is introduced into the soil (to a depth of 10–15 cm), there is an active interaction (sticking), soil and sealant. In the process of primary and secondary expansion of the binder, there is a wedging of foam into the soil, the soil is «absorbed», thus forming a single system of «soil – binder». The expansion of the sealant passed evenly in all directions, and amounted to about 10 cm from the puncture. At the same time, a cylindrical layer of strengthened soil was formed with irregularly shaped edges with a diameter of about 20 cm, which is a monolith of solidified foam interspersed with soil. It was also observed partial protrusion on the surface, with the formation of a «cap» of frozen foam. The sample section is shown in Figure 3.

![Figure 3. Slice of soil sample reinforced with polyurethane foam sealant](image)

With additional mechanical mixing of the soil and the injected foam, immediately after injection into the soil, a layer of reinforced soil was formed with more evenly distributed soil particles.

Technology of production for strengthening the soil of the subgrade transportation construction with polyurethane foam sealants includes three main operations:

1) Preparation of the ground base of the subgrade.
   1.1. The device of pavement in the recess includes excavation to design level (10 cm below the sole of the pavement), followed by planning.
   1.2. The device of the pavement mound include: raising the body of the mound up to design level (10 cm below the sole of the pavement), followed by planning.

2) Putting a binder.

   The binder is introduced into the ground by injection, using a special frame with spikes mounted on construction equipment (see Fig. 4). The spike is immersed in the soil to a depth of 10–15 cm, after which the sealant is injected.

   The spikes are fixed on the frame of the working body of construction equipment. Sealant is supplied from the cylinder to the working body occurs through special tube-channels.

3) The device of the protective-leveling sand layer.

   Distribution of a protective-leveling sand layer with a thickness of 10 cm, according to the technology «Push», with compaction and layout. The compaction of the layer should begin not earlier than 8 hours after the introduction of the binder. Then we arranged a pavement.
2. **Summary**

1. According to the results of this work, it can be concluded that the method of strengthening the soil with polyurethane foam sealant is relevant, promising and more effective, compared with the applied ones. Due to its simplicity, extensive scope, fast and high-quality final result, the method will be in demand in the field of road and civil engineering.

2. Polyurethane foam sealant refers to the condensation type, which means it is less sensitive to impurities in soils and oxygen, which significantly expands its scope.

3. The resulting building material is characterized by a low coefficient of thermal conductivity and allows:
   - significantly reducing the thickness of the additional layer of pavement;
   - providing a stable water-heating regime of the subgrade;
   - maintaining the high strength characteristics of the subgrade at the level of strength of the soil components at optimal humidity;
   - preventing frost heave of the subgrade.

4. The conducted trial experience of strengthening of the soil with a sealant showed the effectiveness and efficiency of the proposed method. Ease of entry into the ground and the speed of strength can ensure continuity of construction and installation work on the sections of the route with specific soils.

5. The technology of work on strengthening of the soil of the subgrade of transport facilities with polyurethane foam sealants is easy to use, allows getting the desired result in a short time and does not require special expensive equipment.

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