To the question of strength and stability increasing of thin retaining walls

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Abstract. The features of structural and technological solutions of strength and stability increasing of thin retaining walls and reinforcement of the backfill soil, dam, and slope are considered. Glassfiber concrete was proposed as the material for the wall which, as compared with ordinary concrete, has enhanced performance characteristics. Despite the variety of solutions for soil reinforcement and ways to minimize horizontal deformations, a new technological solution has been developed to increase the stability of the walls while increasing the additional load on the soil within the pressure prism. It is given the description of this solution and the results of experimental studies in confirmation of the theoretical assumptions about the improvement of the physical and mechanical characteristics of the backfill soil during the construction of retaining walls.

Introduction
The length of roads in the Russian Federation is more than 1.5 million km. More than 50 thousand km are federal highways. Retaining walls are the most common types of engineering structures in transport construction. They are erected with the purpose of strengthening of the slopes of embankments and hollows of roads and railways, as anti-dumping and anti-landslide structures, to protect the roadbed from erosion, as well as during the construction of embankments and mooring facilities.

Despite the variety of retaining wall designs and ground reinforcement technologies known to date, many of them have certain disadvantages such as: technological difficulties, increased requirements for the physical and mechanical characteristics of the backfill, a large proportion of manual labor, the need for special equipment, high material consumption.

The material for massive retaining walls is usually concrete. In case of a structure with thin-walls additional reinforcement is necessary. Along with wire screen and frameworks, dispersed glass fiber reinforcement [4] and, if necessary, carbon fibers, have recently been used [6].

Being a composite, glass fiber concrete combines the positive properties of a concrete matrix concerning high compressive strength, and at the same time, due to the inclusion of glass fiber in the work, it has enhanced crack resistance, water resistance, and operational durability compared to ordinary concrete. While concrete weakly resists tensile forces, fiber-reinforced concrete of a similar brand may have a tensile strength in bending in comparison with concrete 4-5 times higher, axial tension higher 3-4 times, impact strength 15-20 times higher and this is important for the operation of a significant part of the supporting structures, including thin retaining walls.

For glass fiber concrete structures, structural fine-grained concrete of average density of 2300 kg/ m³ on quartz sand with grain size from 1.5 mm to 2.3 mm is provided. Portland cement, alumina cement of brands not lower than M400, as well as micro silica additives or binders of low water demand are used as binders for the preparation of fine-grained concrete of glass-fiber-concrete structures.

Fiber in the form of glassfiber pieces, usually with a length of 10 to 60 mm, for glassfiber reinforced concrete produced by cutting:
- roving of alkali-resistant (cement-resistant) fiberglass;
- roving of aluminosilicate (non-alkali-resistant) fiberglass.

The length of the fiber is taken depending on the size and percentage of structures reinforcement, the type of technological equipment for the preparation and laying of glass fiber concrete mixture.

For the reinforcement of fine-grained concrete on Portland cement, alkali-resistant fiber is used. A non-alkali-resistant fiber is used to reinforce concrete based on alumina cement, Portland cement with the addition of gypsum or micro-silica for a limited service life.

Main part

It seems to be an actual problem of fiber concrete optimization. The fibers saturation should be subject to the design force scheme. In other words, management of structure formation process should have a subsystem of stress-strain state predicting the behavior of the structure in real conditions.

Supporting glass fiber-reinforced concrete elements, which include mostly the elements of thin-walled structures, as a rule, have a combined reinforcement. The fibers are combined with rod-shaped, wire steel reinforcement or rod-shaped fiberglass reinforcement.

Steel rod or wire reinforcement, uniformly distributed across the thickness of the section, can be taken into account by reducing it to fiber reinforcement [6]:

$$R_t / R_{fbt} = \mu_f + \mu_s$$

where $\mu_f$ – fiber reinforcement coefficient by volume; $\mu_s$ – steel reinforcement coefficient; $R_t$ – design resistance of glassfiber reinforced concrete strength; $R_{fbt}$ – design resistance of steel reinforcement strength.

$R_{fbt}$ is based design resistance of fiber reinforcement strength $R_f$. It is corrected by coefficients which take into account: the concrete matrix effect on fiber-reinforced concrete strength, fibers saturation by volume, fibers orientation, their length influence and working conditions. They mean the duration of action and the repeated frequency of the load, environment aggressiveness, structure manufacturing method, etc.

The coefficient of fiber reinforcement by volume is recommended to be taken within $0.01 \leq \mu_f \leq 0.05$. It is allowed at the economic substantiation to take $\mu_f > 0.05$, when increased requirements are imposed on the structure in terms of crack resistance.

Despite the diversity of soil reinforcement solutions and ways to minimize horizontal deformations, it was developed a new design and technological solution to increase the stability of the retaining wall. The task is to increase the stability of the retaining walls with an additional increase in the load on the soil within the surface of the pressure prism. This is achieved as follows. Along the vertical slope 1, a retaining wall 2 is installed either from foundation blocks or in the form of thin sectional reinforced concrete vertical slabs with a penetration in the soil. If the slope is inclined, then loose soil is filled up behind the wall with compaction. After a certain step along the wall within the pressure prism 3, the inclined plane of which is determined from the base of the wall at an angle $\alpha = 45^\circ - \phi / 2$, where $\phi$ is the angle of internal friction of the soil, vertical wells 4 are drilled, into which cylindrical screwed pipes 5 from polymeric material 1 m long, on diameter of wells. Preliminary, circular triangular nicks 6 are made inside them, in the notched bottom, and a plug 7 is placed in the lower part of the common screwed pipe, and connecting pipe 8 with threading for screw of delivery hose into the upper part, through which the hardening solution is injected (into loam-silicate, in sands - based on carbamide resins of the KFMT brand), forming radial, areal fracture cracks 9, filled with hardening solution, forming flat, circular elements 10 in them, which reinforce the soil (Figure 1).

![Figure 1. Scheme of constructive and technological solutions to increase the stability of the retaining wall](image-url)
Moreover, the wells are drilled at a distance equal to one third of the base of the pressure prism 3 from wall 2 (Figure 1).

Hydro fracturing pressure $P_{fp}$ must be higher than domestic pressure $P_d$:

$$P_{fp} = 1.44 \cdot P_d [kPa]$$

(2)

where $P_d = \gamma \cdot h$, where $\gamma$ is specific weight of the soil above the fracturing plane; $h$ is depth from surface to hydro fracturing plane ($h=1/3 H$), and the injection pressure of the solution into the fracture crack is assumed to be 0.77 kPa from domestic:

$$P_i = 0.77 \cdot P_d [kPa]$$

(3)

In order to confirm the theoretical assumptions about the improvement of physics and mechanical filling soil characteristics during retaining wall construction or embankment soil, slope, dam, the soil was reinforced at the experimental grounds of the Belgorod region.

This method is based on the injection compaction of soils by delivery using a special technology of cement solution under pressure, which significantly exceeds the load on the soil.

After strengthening, the frozen cement solution forms a reinforcing frame which looks like the roots of a tree, “trunk” of which is the injector immersed in a soil (with the frozen cement solution in the injector) (Figure 2). An additional improvement in the soil mass characteristics takes place. The high selectivity of sealing solution allows to strengthen the weakest zones of the soil to the maximum extent, creating practically homogeneous array with a high bearing capacity.

![Figure 2. Soil reinforcement](image)

This technical solution for soil reinforcement provides: an increase in strength and deformation characteristics of bulk soils; alignment of physical and mechanical characteristics; soil stabilization with preventing the development of deformation; soils water protection increasing.

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