Effective technology for strengthening natural slopes and artificial structures

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Abstract. The problems of strengthening mountain slopes, slopes of artificial structures and banks of water bodies are considered. The methods, materials and structures used for this purpose are given with a brief description of the work performance techniques. The experience of protecting mountain slopes due to the force inertial compaction of the concrete mix prepared in a special hermetic high-speed compulsory concrete mixer is indicated. The mixture under pressure is uniformly transported along the material line at a speed of 120-200 m/s to the nozzle. The schemes of the force inertial compaction of the concrete mix and the composition of a mechanized complex for its preparation, transportation and application are considered; recommendations are given on the composition of the team and its functions. The method of dry concreting under high pressure ensures environmental friendliness, which eliminates the need for using respirators and other protective equipment and expensive treatment plants.

1 Introduction

Strengthening mountain slopes and slopes of artificial structures and banks is the most important task of preserving territories with complex terrain [1, 2]. In such areas, soils are erosion prone, landslides and soil displacement, rock falls and snow avalanches occur [3, 4]. The banks of water bodies and the surface of gullies are also very mobile, since there are clay soils under their upper layer. To prevent these negative effects, a variety of natural and artificial methods of strengthening are used, each of which is characterized by features and conditions of use [5, 6].

Today, a variety of measures are used to protect and strengthen mountain slopes, slopes, quarries and hydraulic structures. These measures are aimed at preventing changes in their stress state. Thus, for small inclines of up to 5-6%, prevention of soil erosion can be achieved by planting trees with an extended root system. The methods of terracing, which provide for the construction of retaining walls, for example, most often made of concrete or natural stone, got the widespread use. Such artificial fences are very effective and reliably prevent erosion of soil, especially when they are placed by ledges.

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2 Materials and Methods

Among the popular slope strengthening structures, there are grids, geogrids, and gabions. So strengthening of slopes of terraces is carried out, for example, by double twisting grids, which protect against minor rock falls and snow avalanches. These grids are very strong because they consist of heat treated wire with a polymer coating. To prevent larger rock falls and snow avalanches, chain nets consisting of interlocking rings is used [7, 8].

Modern materials used to strengthen steep slopes include geotextile, which is distinguished by its durability and resistance to fungal mold. Geotextiles are laid at a depth of about 50 cm, and then filled with gravel, followed by laying a geogrid with a backfill of sand and paver.

The use of geomats, the design of which is waterproof, is of considerable practical interest. Geomats are a polymeric material that has many voids to fix the roots of trees and shrubs. Canvases of geomats are laid on the slopes after careful alignment and compaction with fastening by anchors.

Among the modern economical and reliable ways to strengthen the slopes is the technology “Concrete Canvas”, i.e. laying of concrete canvas. Concrete canvas is two textile layers with a cement mixture inside. The outer fibrous surface absorbs moisture well, and the inner side of the canvas is covered with a waterproof PVC layer. Such a canvas is spread on the cleaned surface, fixed and then wetted. As a result, after 2-3 hours, the cement mixture solidifies and a very strong reinforced concrete surface is obtained.

The use of different methods and structures to strengthen mountain slopes and slopes of artificial structures requires certain costs and each of them has its own area of rational use. In this regard, new technologies are being developed and experimentally studied. These technologies, alone or in combination with other methods, allow achieving high indicators. One of such promising technologies is the engineering protection of the surface under high pressure in a water aerosol environment. For the first time such a technology was used in 1993 in Kislovodsk by the PCC “Grantstroy” to protect the mountain slopes of the “Elbrus” health resort. The whole process of concreting a volume of 4.4 thousand m$^2$ with a thickness of 10-15 cm was made in 30 calendar days [9] by one team of seven people.

3 Results

At the first stage, experimental works were performed on the area of 2.8 thousand m$^2$ with preliminary cleaning of surface, laying and anchoring a special metal grid with a cell of 50 x 50 mm, and making up a reinforced concrete surface by shotcreting at high pressure. At the same time, an organized storm drainage system was created. After a thorough assessment of the operational parameters guaranteeing the required quality and reliability of the mountain slope protection, work was performed on the rest of the surface, and it was the second stage.

This technology includes the force inertial compaction of the concrete mix, which is prepared in a special hermetic high-speed compulsory concrete mixer, in which the speed of rotation reaches 120 rpm, and at a pressure of more than 1.4 MPa, the concrete mix is transported at a steady pace without pulsations along the material line at a speed of 120-200 m/sec to the nozzle, to which water is additionally supplied.

A schematic diagram of the force inertial compaction of a concrete mix is shown in Fig. 1.

With this scheme of concreting of the structure, the speed of the concrete mix movement is 4-5 times higher than when using the “wet” method of concreting. As a result, the thickness of the applied layer substantially increases nearly to the design one. This
excludes vibration compaction, since concreting is carried out on the basis of the force inertial effect under high pressure.

![Diagram of force inertial compaction of a concrete mix](image)

**Fig. 1.** A schematic diagram of the force inertial compaction of a concrete mix. Where: I – two-phase flow (crushed stone 10-16 mm, sand 0-4 mm, cement + air); II – three-phase flow (crushed stone 10-16 mm, sand 0-4 mm, cement + air + water); 1 – ultra-high density concrete; 2 – excess water and air displaced to the periphery as a result of the force inertial compaction of the concrete mix.

To prepare a dry concrete mix, cements of grade not lower than 400 are used. The binder consumption for the preparation of a dry mix is 300-550 kg/m³, and for ready mix 350-600 kg/m³, taking into account the loss of material during rebound.

As a fine-grained aggregate, sand of fraction of 0-4 mm is used, amounting to 2/3 of the volume of the mix, and the remaining 1/3 of the mix is formed by crushed stone or gravel of fraction up to 10 mm. If necessary, steel fibers with a diameter of 0.4 mm and a length of 20-30 mm can be inserted into initial mixes, ranging from 4 to 6% of the volume.

The water-cement ratio for concreting is taken in the range of 0.4-0.5.

In some cases, depending on the effect of natural and climatic factors, environmentally friendly additives are added to concrete mixes, which accelerate its setting and solidifying.

The composition of the concrete mix during concreting should be adjusted based on the results of test of the control samples and the rebound value when concreting the surface. In this case, the mass of crushed stone or gravel during a rebound should not exceed 10%.

The beginning of setting of concrete should be within 2 minutes, and the end – within 10 minutes. The strength of concrete after setting is reached up to 40%, and the design one - within 10 days.

The work on high-pressure concreting should be carried out at an ambient temperature of at least + 5 °C.

The components of the mix should be dosed by volume using measuring containers. Dry mixes are loaded into a sealed vacuum system in the following order: first crushed stone and sand, then cement. The mixing time of the components is no less than 1.5 min using a sealed high-speed mixer.

For breaks of more than 20 minutes, the equipment and hoses should be thoroughly rinsed with water (in a wet method of work), and in a dry method of high-pressure concreting, it is necessary to blow the hoses from the mix at the break for up to 6 hours.

### 4 Discussion
When concreting, the amount of water added to the nozzle is dosed by the operator without restriction. His task is to continuously regulate the water content, depending on the amount of bulk material fed through the nozzle, which periodically fluctuates due to the change in the trajectory of the route of the material line, the distance of transportation, the fluctuation in the moisture of the mix, and etc. The amount of water supplied to the concrete mix through the nozzle does not affect the density, since excess water and air are displaced from the concrete body to the periphery due to force inertial compaction of the mix, giving a high density and achieving high physical and mechanical properties in strength.

When working with a nozzle, it is necessary to withstand a strictly defined distance from the nozzle exit to the surface to be coated, the value of which is within 0.5-1.5 m. The specific length of the jet is experimentally determined during the concreting process, assuming a minimum loss of the material bouncing off the surface (rebound). The nozzle should be kept perpendicular to the surface to be coated.

To obtain a uniform homogeneous concrete, the concreting process is carried out by circulating the nozzle in a circular translational motion. In this case, the thickness of the layer formed is inversely proportional to the velocity of the nozzle. Vertical surfaces are concreted from bottom to top using a supporting effect even when applying a mass of material of design thickness.

To ensure high-quality jointing of pours on extended surfaces, the dried edge of the previous pour should be cut so that the newly applied concrete layer at the adjacent section joints the wet section of the stacked layer. When concreting the pours, the coating time of the last one should be 5-8 hours longer than the time for setting and solidifying of concrete with accelerators of setting on the first pours, and 24 hours - in the absence of accelerators.

A schematic diagram of a mechanized complex for preparation, transfer and laying of a concrete mix is shown in Fig. 2.

The method of dry concreting under high pressure ensures environmental friendliness, which eliminates the need for using respirators and other protective equipment and expensive treatment plants.

Fig. 2. A schematic diagram of a mechanized complex for preparation, transfer and laying of a concrete mix. Where: 1 – hermetic mixing chamber; 2 – transfer chamber; 3 – central shaft; 4 – drive; 5 – blades; 6 – replaceable adjustable device; 7 – transfer device for dry mixes; 8 - compressor head with drive; 9 – receiver-shock absorber of compressed air; 10 – skip device.

Work on the shotcreting is carried out by a team of 6-7 people: nozzle operator of 5rd category - 2; plasterer of 4th category - 1; plasterer of 3rd category - 1; plasterer of 2nd category - 1; engineer-operator of 4th category - 1.
The engineer-operator monitors the operation of the mechanized complex and the air pressure, which must correspond to the pressure specified in the standard operating procedure, the signaling functionality and the presence of water in the supply tank. The engineer-operator also takes part in the preparation of a dry concrete mix and its loading.

The main nozzle operator rinses the surfaces, manages the preparation of the mix, applies a shotcrete layer to the surface, monitors the quality of work and performs various auxiliary works.

The second nozzle operator assists the first nozzle operator, and, in addition, is connected with the engineer-operator.

Simultaneously, the second nozzle operator and the plasterer check the hose connections, lay them to the workplace, and prevent outsiders from appearing on the way of the material line.

The plasterers load the mixer of the plant with sand, crushed stone and cement, and prepare a dry concrete mix under the guidance of the engineer-operator. In addition, they fill the supply tank with water from the main water pipe or storage reservoir.

At the end of the work, the plasterer performs systematic watering of the finished surface with water.

Measures to care for the application of concrete depend on the thickness of the coating layer and weather conditions. The main measure is the hydration of the concrete surface by abundant watering, which will allow avoiding ruptures, micro cracks and peeling due to concrete shrinkage.

During the concreting of the surface, it is necessary to maintain a constant visual observation to prevent the formation of clods in a mix of cement and aggregate.

5 Conclusions

By now, various methods, structures and materials for strengthening mountain slopes, slopes of artificial structures and banks of water bodies have been developed and are being applied. In some cases, separate methods are used independently, and in others, as a rule, combinations of different methods.

For effective strengthening of surfaces, engineering surveys are carried out, which allow determining not only the physical and mechanical properties of soils and changes in the groundwater level, but also determining the instability or semi-stability of the slopes.

The complex of engineering measures for strengthening the slopes includes significant amount of work on the cleaning of surfaces, their compaction and strengthening, the creation of a sewage system, and the organization of monitoring the quality of protective structures.

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