SULFUR CONCRETES FOR CARRYING OUT PROTECTION MEASURES AGAINST DISASTROUS AFTERMATHS OF THE ACTION OF WATER ELEMENTS IN EXTREME NATURAL SITUATIONS

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In order to avoid negative results caused by abnormal intensity and duration of the sediments and respectively significant increase of the river level, several options are given to use sulfur-concrete, mixture and molten sulfur for arranging protective units. Sulfur concrete based soil anchors with the drainage systems are suggested for stabilizing the landslide zones. Inexation of the sulfur liquid into the soil holes under pressure is obtainedto reinforce the anti-filter walls.
Suggestions are based on quick hardening feature of the sulfur concrete and sulfur liquid in the structures providing high technical and exploitation features of the buildings and units.

Key words: *Protecting structures, landslide, coastal area, sulfur concrete, extreme situation, protection measure, stabilization*

Climate changes that keep occurring on a global scale in recent years manifest themselves in changes of the intensity of precipitation, the growth of its quantity and fall-out time. Aftermaths of these changes are especially perceptible for countries with a mountainous relief, where the intensity of the water level rise in mountain rivers and also of erosion and mud-stream processes induced by them are directly connected with the precipitation intensity and precipitation fall-out duration.

The buildings and structures with resistance to natural calamities were designed and built on the basis of average statistical many-year observations and, at the present time, in many cases they are not able to withstand the onslaughts of natural disasters with their modern extreme manifestations.

In the agricultural and mountainous areas, especially in the regions remote from the central regions, the river bridges, slope-protecting and other structures are usually built taking into account the 20-, 50- and seldom 100-year average statistical recurrence of a maximal rise of a high water level for a concrete locality.

An abnormally high intensity and an excessively long duration of precipitation fall-out cause a sudden fast rise of the water level in the beds of rivers flowing in narrow mountain gorges and ravines with an upper mark of the water rise much higher than the designed one. The total water discharge from the adjacent gorges and ravines brings about the flooding of large areas with accompanying consequences.

Even in the case of predicted possible catastrophic natural calamities it is frequently impossible due to objective inertness and the shortage of time to withstand the oncoming natural calamities such as floods, mud-streams, erosion of the fertile soil layer and so on.

In such cases, we may place hopes on the structures of passive, or, saying it differently, secondary protection, and also on the increase of the reliability and resistivity level of the existing structures and soil stabilization. But in all cases, including the building of new structures, it is obligatory to increase by one or two orders the value of the maximal

average statistical level of a water rise adopted for a concrete locality (for example, from a 20-year to a 50-year average statistical recurrence).

In order that the structures could be quickly and effectively used in extreme situations, they must be universal, simple and cost-saving and require as minimal time as possible for their construction and putting into operation.

To accomplish these purposes, we can recommend the construction technologies which use sulfur concretes and sulfur grouts.

Sulfur materials and sulfur grouts are building materials, in which sulfur slag (melt) is used as a binding material instead of cement. The same aggregates as in ordinary cement concretes and grouts are used as inert materials.

Sulfur concretes and grouts are practically water-tight, highly frost-resistant, resistant to the action of chemical agents, also possess a high electrical non-conducting capacity. By their strength characteristics, sulfur concretes hold an intermediate position between cement concretes of grade B25 … B30 and highly strong polymer concretes.

Studies of the steel reinforcement quality preservation carried out in the course of 2 years showed that sulfur concrete reliably protects the reinforcement against corrosion in the conditions of properly prepared dense concrete. For a sulfur consumption of 300 … 400 kg per 1 m^3 of sulfur concrete, we get sulfur concretes with compressive strength of 50 … 60 MPa and tensile strength of 7.5 … 9.5 MPa, i.e. with the comparable compressive strength values, the tensile strength of sulfur concrete is almost two times higher than that of cement concrete. The fatigue limit of sulfur concrete is on the average 85 … 90% of the failure modulus as compared with 50 … 55% for cement concrete.

The production process of sulfur concretes insignificantly differs from the asphalt concrete technology and can be organized using the already existing equipment at mobile or stationary asphalt plants.

The sulfur concrete production process includes the mixing of the sulfur melt heated up to a temperature of 160-170^{0}C with an inert material heated up to a temperature of 120-122^{0}C. Sulfur concrete hardens as a result of the crystallization of the sulfur melt by cooling it below a temperature of 120-122^{0}C. In field conditions, this makes it possible to get hardened, ready to withstand operational loads, concrete already 2-3 hours after concrete placement, which is important in extreme situations.

Due to the above-mentioned technological properties of sulfur concretes and grouts, they can be recommended for the use in extreme situations for the quick production and use of protecting poured-in-place structures, separate blocks or monolithic parts of protecting structures. Depending on the purpose and configuration of a produced element, any panels, cut pipe pieces and reprocessed materials and parts of any shape, which can then be left as “permanent forms” in a concreted structure or be used repeatedly as forms.

We should mention one more singularity of sulfur concrete – this is the repeated use of rejected structures which are crushed, re-melted and then moulded.

Fig. 1 shows possible variants of the application of sulfur concretes for making temporary or rehabilitating destroyed bridges, for building water-drainage and protecting embankments, manufacturing blocks for earth-filled dams, coffer-dams and sealing holes in dams and embankments and so on.

Structures and products of this kind made of sulfur concretes and grouts can be used to protect sea shores against being washed out by stormy waves.

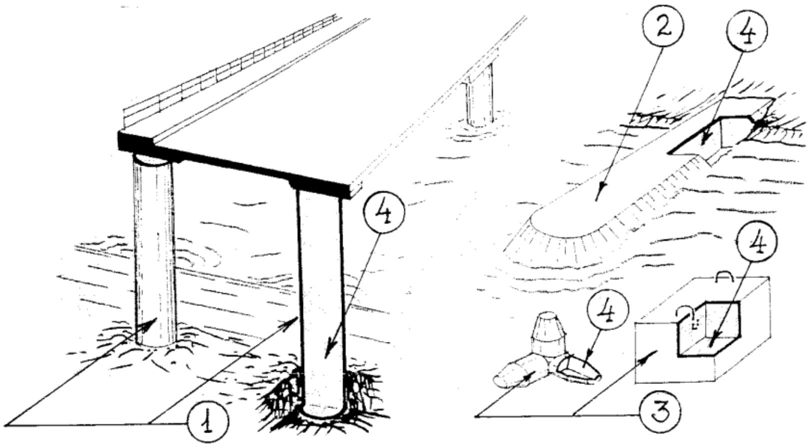

Fig. 1. The application of sulfur concrete when building coast-protecting structures 1 – supports made of pipe cuts filled sulfur concrete and used for restoration of bridges and building of floating bridges; 2 – coastal flood preventing structures (dikes) or breakwater structures with body made of sulfur concrete; 3 – coast-protecting cast-in-situ blocks; 4 – sulfur concrete

In our experiments with sulfur concretes we used heavy- and light-weight sulfur concretes. The compositions and the production process were chosen in conformity with the recommendations given in [1].

In heavy-weight sulfur concretes we used ordinary consolidated aggregates. To prepare light-weight sulfur concretes with an average volume mass up to γo_{cp} = 2000 кг/м^3, we used porous volcanic slag. The aim of the production of light-weight sulfur concretes was to make the average volume mass of the material of the walls of underground and earth-sheltered structures -- for example, of water-tight walls or elements of the core of protecting earth-filled dams and embankments -- to the average volume mass of the earth environment. This helps to prevent possible subsidences of structures and the development of deformations and stresses that cause crack formation, and also to protect structures and the surrounding earth medium against the action of both underground water and seismic forces.

Table 1 gives the following strength characteristics of heavy- and light-weight sulfur concretes: compressive strength R_b, bending strength $P_и$, and the concrete crack resistance index – the critical coefficient of stress intensity K_{Ic} obtained by testing small-sized beams with a bending cut according to the scheme of a three-point application of load.

Strength characteristics and the crack-resistance index K_{Ic} of sulfur concretes

Table 1

Sulfur concrete aggregate	γo_{av}, kg/m^3	R_b, MPa	$P_и$, MPa	K_{Ic}, MN/M$^{3/2}$ by experiment	K_{Ic}, MN/M$^{3/2}$ *)
Heavy-weight	2347	36.1	9.1	1.135	0.52
Light-weight	2000	33.2	7.7	0.73	0.45

***) From the technical literature for cement concretes of the corresponding strength grades.**

The above characteristics testify to sufficiently high strength characteristics of sulfur concretes. This especially concerns the crack-resistance index, which guarantees their

reliability when they are used as a material for building water-tight walls and other earth-sheltered and underground structures.

An increase of the non-standard intensity of precipitation fall-out essentially affects the stability of a soil state. The moisture content and the soil capacity for saturation with its large-amplitude changes contribute to the destabilization of soil. The load-bearing capacity and the binding property of soil decrease essentially.

There are many various techniques for soil stabilization [2]. Among them, cement injection and silicatization have found the widest application in practice. The bituminous grouting of soil is also used [3,4]. Each of these methods has its own application limits and thus none of them can be regarded as fully universal. Each of them has both advantages and shortcomings.

The gist of the bituminous grouting method consists in that the melted bitumen is injected through the bored holes into soil and, after cooling in cracks and inter-grain cavities, it imparts the rock the water-proof property even in the presence of high underground water flow velocities.

However this method has some disadvantages:

- as time goes by, bitumen gets squeezed out from the cracks under the pressure of underground water;

- soil water permeability does not decrease completely;

- essential shrinkage.

For soil stabilization we can recommend the impregnation of soil with the sulfur melt as proposed in [5]. The gist of this method consists in that the sulfur melt heated up to a temperature of 130 ... 170^{0}C is injected into soil to a given depth through the bored holes or by means of special injectors. The sulfur melt injection is done using the methods and equipment used for the hot bituminous grouting of soil but with a slight modernization taking into account the peculiarities of preparing the sulfur melt and its technological parameters.

An experiment was run on the injection of the sulfur melt into sand soil of average density, with a maximal grain size of 2.2 mm. The designed resistance value of the foundation on this soil is 0.25 MPa.

During the experiment, after finishing the injection work, the results of specimen tests gave an average strength value of 6.2 МПа for the soil stabilized by the sulfur melt. For comparison: a maximal strength of bitumen-soil and bitumen-sand mixtures is 2.0 … 2.6 MPa [3], while a maximal strength of the soil grouted with bitumen is 4 MPa [4].

As compared with the known methods, the proposed method of soil stabilization has a number of advantages including:

- a quick gain in strength immediately after the sulfur melt is cooled down to the ambient temperature, which needs only 1.5 … 2.0 hours;

- the absence of water absorption by the soil which is inherent in the cement grout injection and the soil stabilization with chemical agents which result in soil subsidence;

- high strength characteristics of the stabilized soil.

In addition to this, it is necessary to take into consideration that in the countries which consume and refine oil and gas, sulfur is a waste product and its recycling is a serious problem. Therefore the use of sulfur as a waste product of the oil and gas industry is advisable from both economical and ecological standpoints. These facts testify in favor of cost-effectiveness of the proposed method of soil stabilization.

Fig. 2 shows some variants of the application of the proposed method of soil stabilization in several situations.

With the purpose of nature preservation the proposed method can be recommended to be used for

- taking measures of preventing mud-slides (see Fig. 2);

- protecting slopes against water and wind erosion;

- taking measures of decreasing soil slump;

- decreasing soil filtration (see Fig. 2);

- fixing cracked soil, sand soil and broken rock;

- decreasing suffusion in filterштп rock.

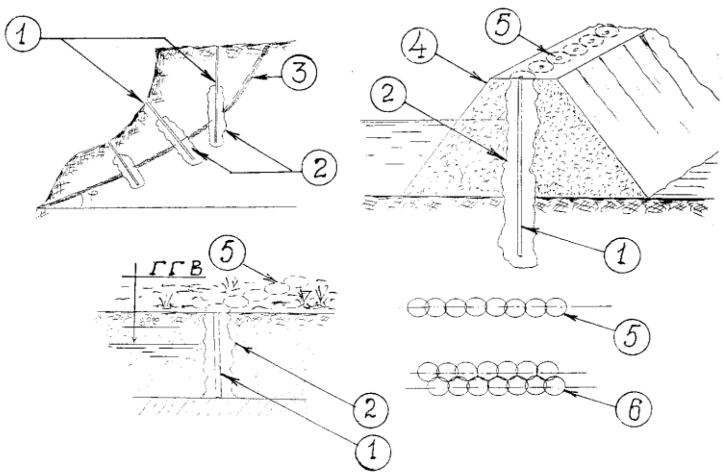

Fig. 2. The application of the sulfur melt for soil stabilization
1 – blast-holes for injection of sulfur melt into soil; 2 – soil areas stabilized by sulfur melt; 3 – sliding plane of soil in the case of slope collapse; 4 – earth-filled dam or gravity dam; 5 – one-row, in plan, injection of sulfur melt into soil when building water-tight walls; 6 – two-row, in plan, injection of sulppur melt into soil when building water-tight walls

The soil soaked with water as a result of durable and intensive precipitation fallout, especially in sloping localities and on mountain slopes, as well as on not stabilized road embankments are fraught with danger of unexpected landslides, especially in regions with a high seismic activity.

To prevent the development of mud flow processes which may be caused by the soaked soil of natural and already built slopes, we can recommend the application of the so-called "drainage earth anchors" [6].

Traditionally, drainage systems are used for soil draining, while the stability of slopes is provided by building the retaining walls and installing ground anchors, see Fig. 3.

In [6], it is proposed to use the device which combines the functions of a ground anchor and a drainage system. The anchor root with a reinforcement tie is embedded at the designed depth by the well-known technique. On the anchor part which is between the supporting plate on the slope surface and the anchor root, a drainage system is installed in the anchor body, which allows the filtered underground water to pass through it. The filtered underground water flows from the proposed device with combined functions either

through the holes made in the supporting plate in that part of the device which performs the function of the anchor or through the pipe or the batter which passes outside the supporting plate, see Figs. 4 and 5. The technical result consists in the following simultaneous processes: the moisture content of the slope soil decreases, while the soil density increases and this prevents the soil displacement. To speed up the process of anchor installation, sulfur concrete can be used instead of ordinary concrete for fixing the anchor root in its position.

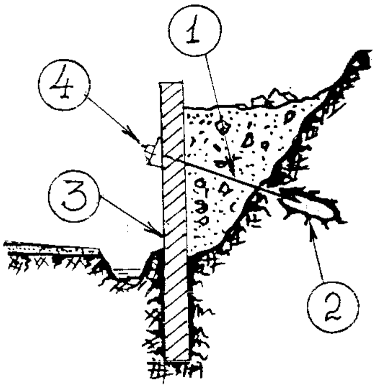

Fig. 3. Stabilization of road embankments by the supporting wall fixed in the foundation and by the earth anchor:
1 – anchor tie; 2 – anchor root made of sulfur concrete with embedded anchor tie; 3 – retaining wall; 4 – fixing device of anchor tie

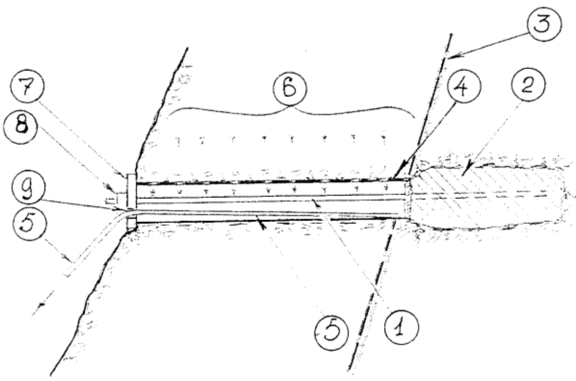

Fig 4. Draining earth- anchor with a hollow perforated drain-pipe:
1 – anchor tie; 2 – anchor root made of sulfur concrete with embedded anchor tie;
3 – sliding plane of earth in the case of slope collapse; 4 – perforated hollow drain pipe;
5 – pipe (hose) for draining filtered underground water; 6 – moisture filtering from soil;
7 – anchor supporting slab; 8 – anchor tie fixing device; 9 – hole through which moisture flows

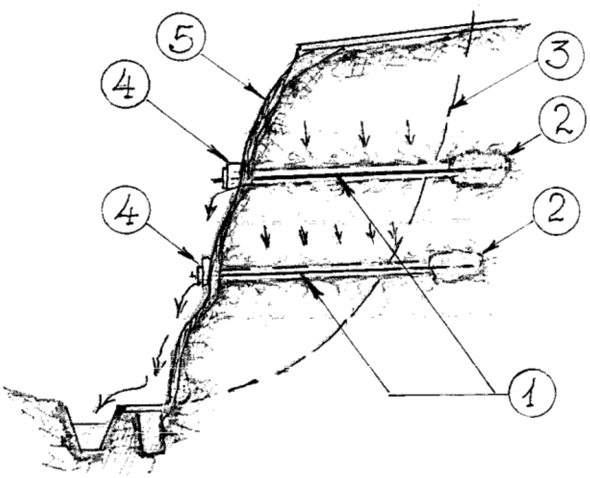

Fig. 5. Tier-by-tier arrangement of soil drain anchors on the slope during its stabilization:
1 – anchor tie; 2 – anchor root made of sulfur concrete with fixed anchor tie; 3 – sliding plane in the case of slope earth collapse; 4 – anchor tie fixing device; 5 – protecting erosion-prevention membrane made of gun-concrete on metal grid and installed on slope

For the urgent use of sulfur concretes and grouts in emergency situations, they can be transported to the required site in the state of a dry mixture, for example, in metal containers. Dry mixtures ready for the application can be heated up to a needed temperature in the same metal containers at the site of their application.

In localities, where there potentially exists a danger of unexpected natural disasters, the preliminarily prepared dry mixtures of sulfur concretes and sulfur grouts can be stored so that they can be used when a necessity arises to prevent or liquidate the aftermaths of natural disasters.

R E F E R E N C E S

1. **Paturoyev V.V. Polymer concretes. Moscow:** ***J. Stroit. Industria*** **, 1987 (in Russian).**

2. **Rzhanitsin B.A. Chemical stabilization of soils in civil engineering. Moscow:** ***J. Stroit. Industria.*** **1986 (in Russian).**

3. **Shestoperov S.V. Шестоперов С.В. Road-buiding materials. Moscow: Visshaya Shkola Press. 1969 (in Russian).**

4. **Goncharova L.V. Foundations of artificial stabilization of soils. Moscow University Press. Moscow 1973 (in Russian).**

5. **Loladze G.V., Loladze V.V. Method of soil stabilization. Patent No. U1490. Official Bulletin of Industrial Property. No. 23(67). 2008. Tbilisi.**

6. **Loladze G.V., Loladze V.V. Грунтовый анкер for stabilization of slopes. Patent No. P 5294. Official Bulletin of Industrial Property. No. 18.0 2011.09.26. Tbilisi. 2011.**