

# Ensuring the Stability of Channel Linings Under Unsteady Filtration

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**Abstract:** When assessing the stability of the slopes of the banks of reservoirs and channels, the filtration regime that occurs with a rapid decrease in the water level in the upstream, which is due to the nature of the operation of structures before floods, discharges, emergency situations, is of particular interest. A change in the water levels in the upstream causes a change in the position of the depression surface and the parameters of the filtration flow (pressure gradients, filtration rates and flow rates) in the coastal massif. At the same time, unsteady filtration occurs in the coastal massif and the stability of the slopes is reduced significantly due to the action of hydrodynamic forces directed towards the slope.

The most reliable anchors of channel slopes in similar conditions are those that, under normal channel operation, when there is no groundwater support, the lining should exclude filtration from the channel, ie filtration losses of irrigated water, and if there is a backwater and with a rapid decrease in the water level in the channel, it should provide free access of the ground stream into the channel channel or its diversion in the other direction. This eliminates the occurrence of significant hydrodynamic pressures, and the destruction of the channel slope fasteners.

The article presents the results of studies of 4 designs of channel linings operating under conditions of unsteady filtration. In the course of the study, we considered the following variants of structural schemes of linings. Fastening with combined deformation and filtration seams; fastening with self-collapsing seams; fastening with discharge tubular drains with water discharge into the channel; fastening with filtration and discharge holes arranged during the appearance of groundwater backup in the channel area.

The results of calculating the stability of the fastening plates for overturning and surfacing are presented. According to the results of the calculation, the most acceptable fastening options are determined, their advantages and disadvantages are given. The proposed fastening design meets the above requirements and thereby ensures the strength and stability of the linings during the operation of the channel.

**Keywords:** channel, slope fastenings, channel lining, filtration, reliability, durability, drainage device, slope stability, false seams, rapid water level drop in the channel.

## 1. INTRODUCTION

When assessing the stability of the slopes of the banks of reservoirs and canals, of particular interest is the filtration regime that occurs when the water level in the upstream rapidly decreases, which is determined by the nature of the operation of structures before floods, discharges, and emergency situations.

A change in water levels in the upstream leads to a change in the position of the depression surface and the parameters of the filtration flow (pressure gradients, filtration rates and flow rates) in the coastal massif. In this case, unsteady filtration occurs in the coastal massif, and the stability of the slopes is significantly reduced due to the action of hydrodynamic forces directed towards the slope.

In the practice of operation of hydraulic structures of irrigation and drainage systems, deformations of the bases were observed, and there were also local violations of the stability of the slopes of lined and unlined canals. Often, the violation of stability led to accidents [1,2,3].

Usually, the canal routes run in cuts of various depths, in difficult engineering-geological and hydrogeological conditions. Initially, the groundwater level in these areas is below the level of the canals. Therefore, the task at the first stage of operation of structures is to exclude filtration losses from the channel. In the future, due to infiltration from the upstream canals, reservoirs and irrigation of adjacent territories, groundwater is fed and the level of groundwater can rise above the canal mark.

Obviously, such a situation can lead to adverse consequences, especially with a rapid decrease in the water level in the canal. At the same time, significant hydrodynamic water pressures will have to act on the lining, which can cause the destruction of slopes. Therefore, the study of the issue of protecting the lining of canals from the effects of these seepage waters is of great practical importance.

The most reliable fastenings of canal slopes under similar conditions are those that, during normal operation of the canal, when there is no backwater from the side of groundwater, the lining should exclude filtration from the canal, i.e. seepage losses of irrigated water, and in the presence of backwater and with a rapid decrease in the water level in the canal, it should ensure the free exit of the ground flow into the canal bed or its diversion to the other side. This eliminates the occurrence of significant hydrodynamic pressures, and the destruction of the fastenings of the channel slopes. In some sections of the canal, the groundwater level is above the water horizon in the projected canal. In this case, significant hydrodynamic groundwater pressures will have to act on the lining, which can lead to uplift of individual plates and disruption of the integrity of the channel lining.

In recent years, some progress has been made in the development of structures for supporting the slopes of canals and earth dams. Various new designs and fastening methods have been developed and tested under production conditions.

In a number of cases, a sufficient measure against the destructive effect of filtration is the device of surcharges in the form of a layer of coarse-grained material. In more difficult conditions of exposure to filtration and hydraulic flows, it was necessary to install coatings made of concrete, reinforced concrete, asphalt concrete and other structures for fixing slopes that could resist significant mechanical stress [3].

Nevertheless, the listed fastenings are necessary and sufficient conditions for ensuring non-filtering slopes. For filtering slopes, this condition is not enough. It is necessary to create new structures in which it is necessary to additionally use the filtration effect of various types of drainage, which consists in the complete or partial repayment of filtration forces on the surface and in the body of the slopes.

The main direction in the development of new solutions should be considered the combination of mechanical, filtration and drying effects with rational and economic designs of fixtures and drainages, which make it possible to achieve the necessary stability of slopes in unstable soils.

An analysis of the materials of published works and patent information search showed that the developed design solutions for fixing slopes are associated with an increase in the reliability of their operation when operating in various hydraulic and hydrogeological modes. Based on this, they can be classified and some types can be combined into three separate groups:

- 1) filter mounts;
- 2) impervious or slightly permeable coatings;
- 3) covers with filtering devices and valves.

When choosing one or another type of fastening, the following conditions for their operation are distinguished: 1. High groundwater level (GWL) and low water level (LW) in a reservoir (canal, reservoir) canal; 2. Low GWL and high HC in the reservoir; 3. Variable GWL and SW in a reservoir with design positions under conditions 1 and 2.

At high GWL and fast drawdown of water in the reservoir, filtering types of fastenings 1 and linings with filtering devices 3 are most acceptable, providing additional water inflow into the reservoir and reducing the weighing filtration pressure on the lining.

Under conditions of low GWL and high HC in the reservoir, impermeable or slightly permeable types of linings 2 are most acceptable, which exclude filtration losses. Under conditions of variable hydraulic and hydrogeological regimes, it is preferable to use coatings with filtering devices 3 or devices that act as valves and, less often, impermeable or slightly permeable linings 2.

## 2. METHOD

In connection with the foregoing, it became necessary to develop a special design scheme for lining in relation to the conditions of the main canals located in various engineering geological and hydrogeological conditions, which would satisfy the above requirements.

In the process of research, we considered the following options for the design schemes of linings. In some of them, patents of the Republic of Uzbekistan were obtained.

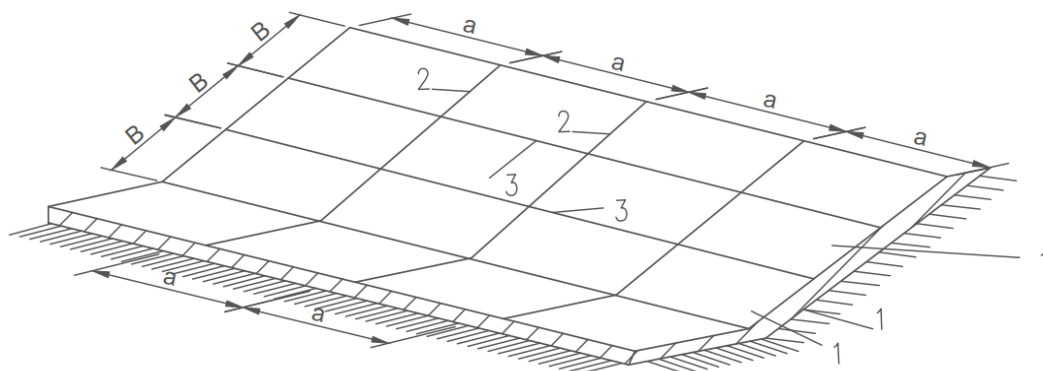
- fastening with combined deformation-filtration seams (option 1);
- fastening with self-destructive seams (option 2);
- fastening with unloading tubular drains with water outlet into the channel (option 3);
- fastening with filtration-unloading holes, arranged during the period of occurrence of groundwater backwater in the canal zone (option 4).

For options 1 and 4, patents of the Republic of Uzbekistan were obtained [6,7,8,9]. We have developed a technique for their filtration calculation and determination of the lining design parameters.

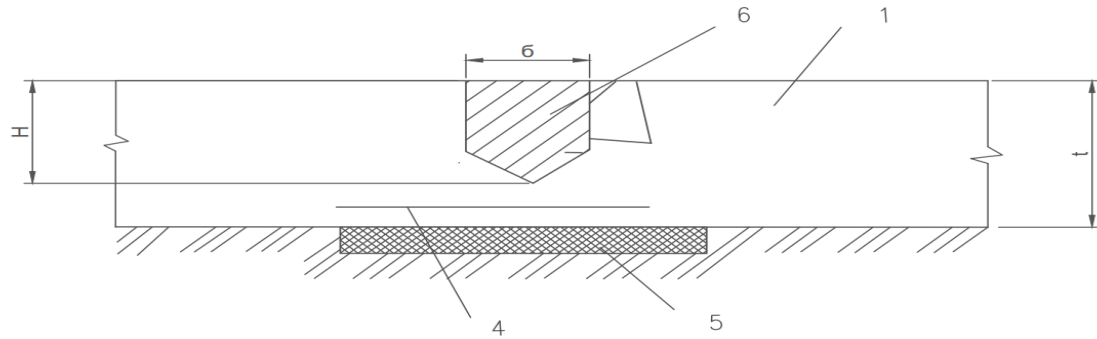
The first option (patent RUz. No. 315) includes a monolithic concrete slab and a drainage device (Fig. 1) . The drainage device is made in the form of transverse and longitudinal false seams of a weakened section, equipped with sliding reinforcement placed within the slab between the seam and the filter [6]. When, for example, a canal is filled with water and there is no groundwater backwater, filtration from the canal is excluded due to the integrity of the lining. When the groundwater level rises above the water level in the channel, a backwater is created on the concrete slab of the slope lining, and as a result of the pressure difference, the false seams crack and diverge to certain limits due to the presence of sliding reinforcement, the groundwater enters the channel through a filter that prevents soil suffusion, removing hydrodynamic pressure on the channel slope lining.

We have developed a filtration calculation of channels with such fixtures [10].

A)



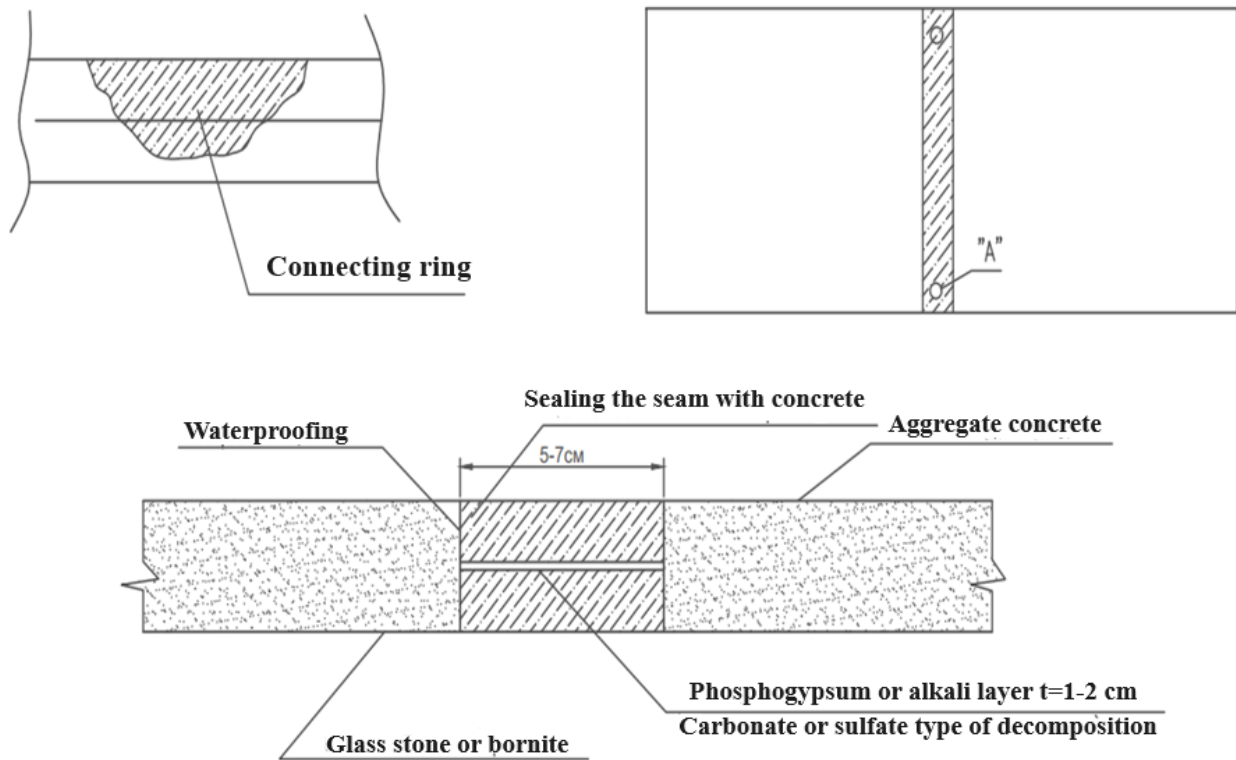
b)



**Fig.1** Combined deformation-filtration seam. a) general view; b) node I 1-monolithic concrete; 2-transverse seams; 3-longitudinal seams; 4- fittings; 5-filter made of artificial fiber materials; 6 board.

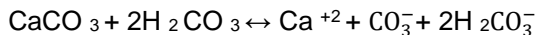
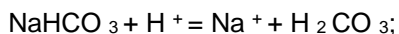
In the second variant, the design of the seam differs from the previous one in that, in contrast to it, the destruction of the seam is achieved here through the application of the following measure. Adjacent plates are interconnected in two places along the seams with the help of special metal rings, as shown in Fig.2.

Geosynthetic materials are laid under the slab - designed to prevent sand suffusion from the base of the cladding during reverse filtration into the channel. The ends of the plates forming the seams are waterproofed with bitumen. In the gap between the plates of a given width (approximately 3-5 cm), a cement mortar is placed to prevent the loss of water for filtration from the channel. In order to achieve the conditions for self-destruction of the weld material, by a certain point in time, a layer of sulfate or carbonate material (soda or phosphogypsum ) is added to its middle part along the height.



**Fig.2** Self-destructive seam

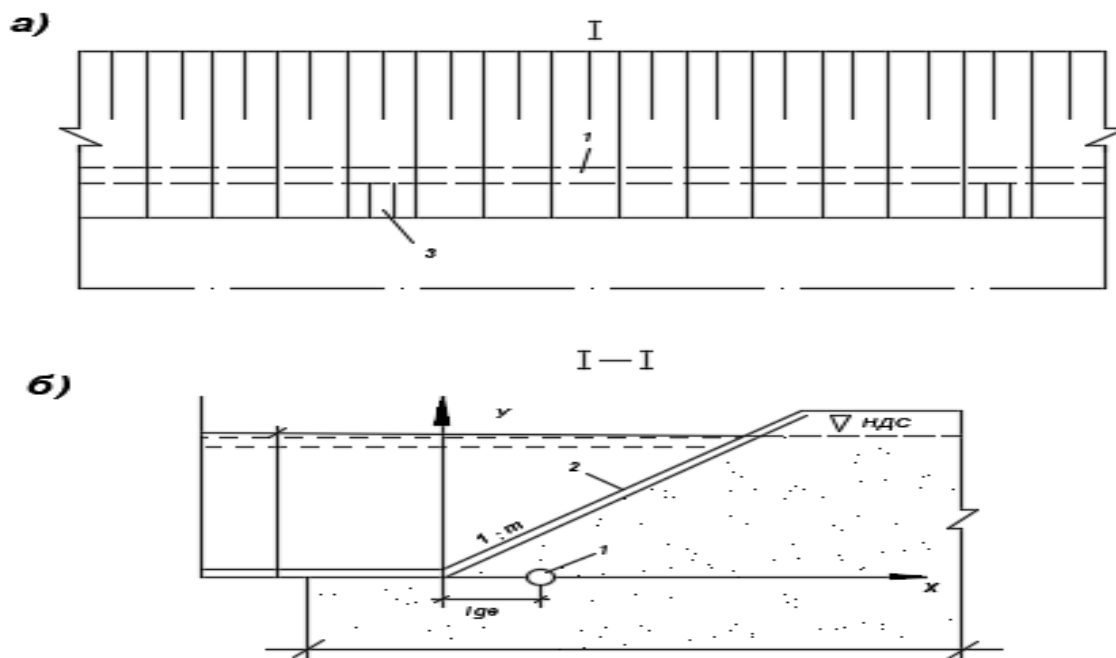
Carbonate aggression of the middle additive on the solution should begin from the channel. With a hardness  $pH < 7$ , excess hydrogen ions  $H^+$  will occur, which will lead, respectively, to the following types of reactions:



The aggressiveness of leaching will be reduced to the dissolution of calcium carbonate and leaching of calcium oxide from the solution. In this case, the minimum content of  $\text{HCO}_3^-$  should be in the range of 0.4-1.5 meq.

The sulfate type of aggression depends on the content of S ions  $\text{O}_4^{-2}$ , as a result of which salts are formed in the solution, leading to its swelling and destruction. With a normal solution, the destruction process will begin when the S content  $\text{O}_4^{-2}$  is more than 250 mg / l. Thus, by selecting the amount of sulfate or carbonate, it is possible to change the time of destruction of the waterproofing joint from the solution.

In the third option, to reduce the hydrodynamic pressure of water on the slope supports, horizontal tubular drains are used, located parallel to the channel at the foot of both slopes and having outlets into the channel at certain distances. The structural layout of such a drainage and outlets in the cross section of the channel is shown in fig. 3.



**Fig.3.** Channel fixtures with horizontal tubular drainage. a) plan. b) section along I - I. 1-horizontal tubular drainage; 2- concrete fasteners; 3-outlets of water into the channel.

Calculations of water inflow into the drainage were carried out by modeling according to the EGDA method on electrically conductive paper. The water inflow to the drains was determined from the hydrodynamic grid constructed from the simulation data. During the experiment, the nature of the effect of hydrodynamic pressure on the slope supports was studied, on the basis of which the optimal location of the tubular drainage was determined. Water intake is carried out by drainage pipes. Ceramic, plastic, concrete and reinforced concrete pipes, porous concrete and polymer concrete pipe filters are widely used as drainage pipes. The calculation results are given [18].

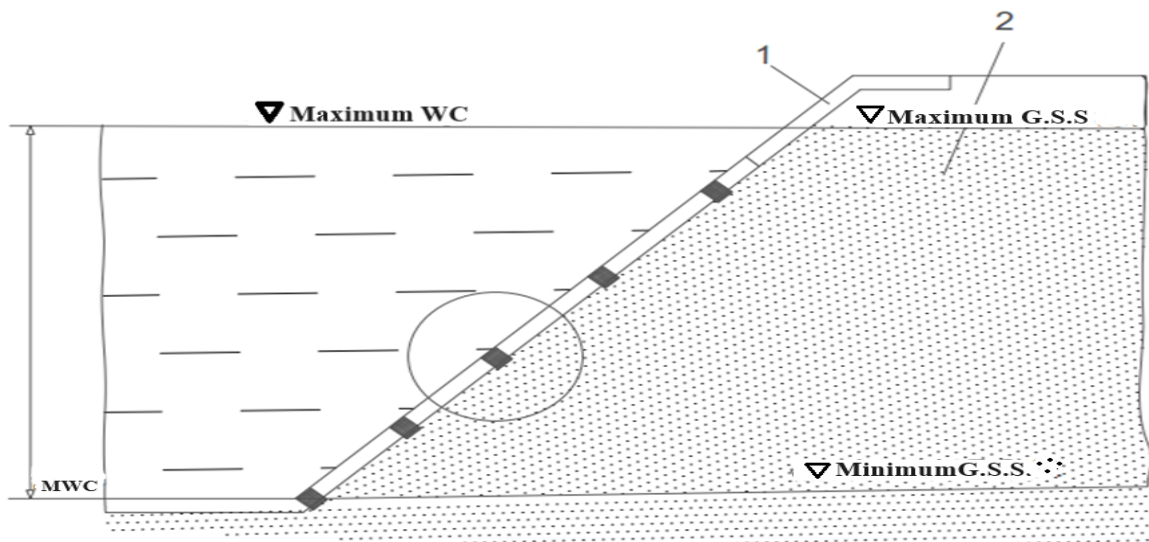
The fourth version of the channel fastening design (patent RUz. No. 316,) is a lining of concrete monolithic slabs laid on the prepared slope soil with filter cups hammered into it. The design of the filtration cup consists of two main parts: a tubular filter and an impermeable head. The tubular filter is a polyethylene pipe with perforations in its lower part, sheathed with filtering non-woven synthetic material such as Dornit or fiberglass. A cap made of a polyethylene pipe with a cork made of a sand-bitumen mixture (asphalt) is put on the upper part of the pipe, isolated from its inner part with a glassine gasket that reduces friction [7]. Figure 4 shows a structural diagram of the channel slope fastening, in Figure 5 filter bowl design

In the initial period of operation of the canal with its maximum level of filling (Max.UV) and in the absence of groundwater under the lining (Low. GWL), it must be waterproof and exclude water losses for filtration from the canal.

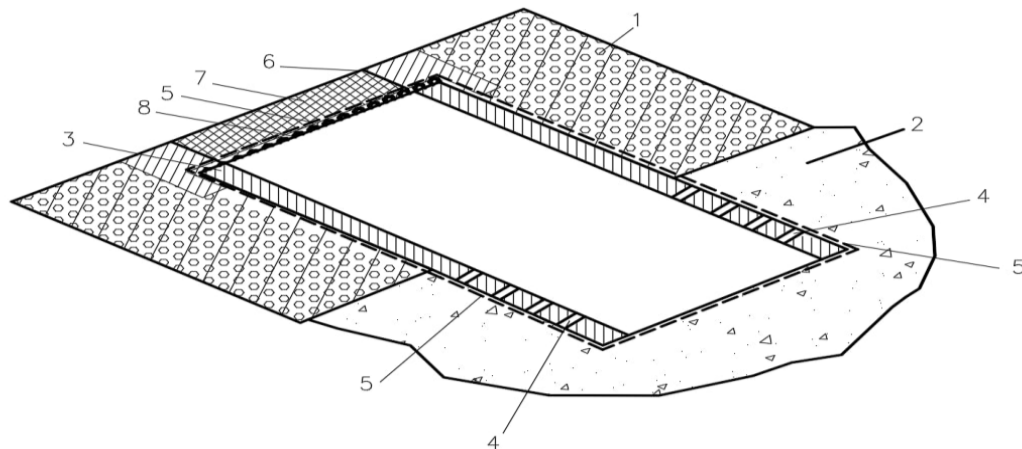
This is achieved by the fact that the filtration holes of the glasses are hermetically sealed from above in the head with an impermeable asphalt plug.

In the subsequent period of operation of the canal, associated with the rise of the groundwater level to its highest standing (Max. GWL), when the maximum filtration pressure, weighing the lining, is achieved with a quick drawdown of the level and the complete absence of water in the canal ( $H=0$ ), the fastening should provide general and filtration stability of the soil slope. This goal is achieved by the fact that under the action of the filtration pressure, the waterproofing plug is automatically pushed out of the hole in the cup head and the ground water quickly leaves the plates, through them into the channel, reducing the filtration pressure. The free exit of the cork from the head is ensured by glassine lining, reducing its friction in the pipe. The arrangement of holes in the lower part of the pipe, buried under the lining in the protected soil of the slope, increases the surface of the water intake zone of the filter, increases the flow rate through the nozzle, and provides a quick decrease in pressure on the lining of the plates. In the future, the filtration cups operate in the usual mode with minor losses or inflows of groundwater into the canal. The filtration strength of the slope, the exclusion of silting of the glasses and the prevention of mechanical suffusion are provided by synthetic filters.

On the basis of the conducted research, we have developed a method for determining the parameters of the proposed slope fastening design [19].



**Fig. 4** Structural scheme of channel slope fastening. 1-concrete monolithic slab; 2- sandy slope soil; 3 - filter glasses.



**Fig.5.** Filtration cup design. 1 concrete slab; 2 - slope soil; 3-polyethylene pipe; 4-perforated holes; 5-filter made of dornite or fiberglass; 6- head of the glass; 7-cork from a sand-bitumen mixture; 8- glassine pad.

### 3. RESULTS AND DISCUSSION

To determine the required distance between the seams, calculations were made of the stability of the fastening plates against capsizing and floating from the hydrodynamic pressure acting on the slope lining when the groundwater level rises. Calculations are performed in accordance with regulatory documents[13]. In calculations, the junction point of the slope attachment with the lining of the channel bottom is taken as a fixed hinge. He marked it with the letter "O". the calculation scheme for the stability of the fixing plates is given in fig. 6. The allowable stability factor is taken equal to  $K_{dop} = 1.1$ .

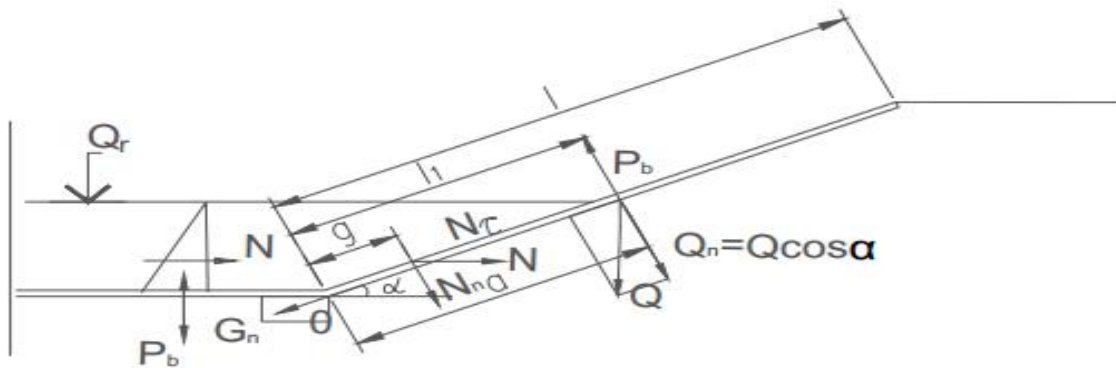
The rollover stability test is carried out according to the formula:

$$K_{opp} = \frac{\ell \delta \gamma_6 \cos \alpha + a + \frac{1}{2} \gamma H^2 \ell_1 \sin \alpha \cdot d}{P_{b,r}} \quad (1)$$

g de  $\ell$  - the length of the plate ;  $\delta$ - plate thickness ;  $\gamma_6$ - volumetric weight of concrete;  $N$ - depth of water in the channel;  $\ell_1$  is the length of the wetted part of the plate;  $P_b$  - total hydrodynamic load;  $a, e, d$ -shoulders of the applied forces.

We check the stability of the mount for floating by the formula

$$K_{вспл} = \frac{\ell \delta \gamma_6 \cos \alpha + \frac{1}{2} \gamma H^2 \ell_1 \sin \alpha}{P_B} \quad (2)$$



#### Rice. Calculation scheme for the stability of fastening plates

Calculations are carried out with an instant drawdown of the water level in the channel, i.e. when  $H=0$ . The values of the effective hydrodynamic pressures of groundwater are taken from the filtration calculations given in [10]. The results of calculations of the stability of the slope plates are shown in Table 1 and the channel bottom in Table 2.

As can be seen from Table 1, with a seam opening thickness of 5 mm, the stability of the slope attachment to floating is ensured only if there is a seam every 1.5 m. and at  $in_{with} = 10$  mm these seams can be made after 2.0 m. Thus, in order for the distance between the seams to be more than 2.0 m, the thickness of the opening of the seam must be at least 10 mm.

As can be seen from Table 2, channel bottom plates with a thickness of 0.2 m are not resistant to floating even if there is a seam every 2.0 m.

**Table 1. Results of slope slab stability calculations**

"b" m	$in_s = 5$ mm		$C = 10$ mm		$C = 20$ mm		$C = 30$ mm		$C = 40$ mm	
	$K_{def}$	$K_{sur}$	$K_{def}$	$K_{sur}$	$K_{def}$	$K_{sur}$	$K_{def}$	$K_{sur}$	$K_{def}$	$K_{sur}$
5	-	-	1.16	0.39	-	-	-	-	-	-
4	-	-	1.50	0.50	1.68	0.56	1.82	61	1.92	0.64
3	1.88	0.63	2.10	0.70	2.36	0.79	2.56	86	2.73	0.91

2.5	2.30	0.77	2.47	0.86	2.95	0.99	3.16	06	3.40	1.14
2.0	2.98	1.00	3.38	1.13	3.85	1.29	4.21	41	4.49	1.50
1.5	4.18	1.39	4.73	1.58	-	-	-	-	-	-

**Table 2. channel bottom plates .**

"b" m	C = 10mm			C = 20mm			C = 30mm			C = 40mm		
	0.2	0.25	0.30	0.20	0.25	0.30	0.20	0.25	0.30	0.20	0.25	0.30
2.0	0.61	0.75	0.89	0.70	0.87	1.03	0.76	0.93	1.12	0.81	1.00	1.20"
1.5	0.85	1.04	1.25	0.98	1.22	1.46	1.09	1.33	1.60	1.16	1.43	1.72

To determine the optimal location of the tubular drainage, which reduces the pressure on the lining to acceptable values, we perform calculations of the stability of the mount plates for capsizing and floating up from the hydrodynamic pressure acting on the slope lining when the groundwater level rises. Calculations are carried out with an instant drawdown of the water level in the channel, i.e. when H=0. The values of the effective hydrodynamic pressures of groundwater are taken from filtration calculations [18]. The results of calculations of the stability of the slope plates and the channel bottom are shown in Table 3.

As can be seen from Table 3, the stability of the slope attachment plates for overturning is ensured in all the considered cases, and for the ascent is also provided except for one case (x=-1, y=-1).

And the slabs, the bottom of the channel, having a thickness of 0.2 m, and 0.25 are not resistant to ascent except in one case (x = -1, y = -1.5). To ensure the stability of the channel bottom plates for floating, it is necessary to increase the thickness of the fastening.

**Table 3. The results of calculations of the stability of the slope plates and the bottom of the channel with tubular drainage**

Tubular drainage options	Slope slabs at $\delta = 0.2$		Channel bottom plates	
	$K_{def}$	$K_{sur}$	$K_{sur}$ at $\delta = 0.2$	$K_{sur}$ at $\delta = 0.25$
X=3 Y=0	3.64	1.56	0.28	0.35
X=4 Y=0	2.90	1.43	0.24	0.30
X=1Y=-1	4.19	2.73	0.62	0.78
x \u003d 0 Y \u003d 1	1.91	1.00	0.48	0.60
X=1Y=-1.5	5.58	3.32	0.69	0.86
X=-1Y=-1	1.79	0.93	0.76	0.95
X=-1Y=-1.5	3.05	1.43	1.09	1.34



#### 4. DISCUSSION

Turning to a comparative assessment of the measures considered here to prevent the harmful effects of groundwater backwater, it should be noted that it is mainly based on a generalization of existing experience and analytical calculations.

The use of the first version of the channel slope fastening design compared to the known ones makes it possible to achieve the following advantages:

- save water by eliminating filtration losses from canals during the period of low groundwater level;
- simplicity of the design scheme and the possibility of combining a number of necessary seams for various purposes - shrinkage, temperature, seismic and subsidence ;
- relatively low labor intensity for the manufacture of seams and the practical absence of operating costs in the process of further operation of the channel;
- the absence of special devices for the diversion and discharge of drained water in the process of reducing groundwater backwater;
- to increase the reliability of operation of the lining and the channel as a whole in conditions of a variable hydraulic regime and a rising level of groundwater.

However, this option has the following disadvantages:

- under the influence of subsidence, sudden changes in temperature, shrinkage phenomena and the seismic factor, premature cracks in the lining and significant seepage losses of irrigated water are possible;
- the impossibility at this stage of accurately predicting the width of the opening of expansion joints and the uniformity of their distribution along the length of the channel in the areas of occurrence of groundwater backwaters;
- lack of guaranteed methods for regulating the crack opening width;
- due to these points, the possibility of a reliable assessment of the volume of filtration losses of water from the canal.

The benefits of option 2 include:

- sufficient reliability of the prediction of crack opening in time, which actually significantly reduces the seepage losses of water from the canal;
- the ability to control the crack opening width by choosing the width of self-destructive seams with the effective operation of both vertical and longitudinal seams on slopes;
- as in the previous version, the absence of special devices for the removal and discharge of drained water;
- low cost of work, also estimated as the average of the compared options.

At the same time, this option has the following disadvantages:

- noticeably greater labor intensity of work compared to options 1 when arranging seams;
- the need to impose increased requirements on the quality of self-destructive seams;
- the need for special materials intended for leaching of the solution of seams;
- the possibility of premature occurrence of cracks due to the reasons noted in paragraph 1 of the previous version and seepage losses of water from the channel, the size of which is also not possible to estimate.

The benefits of option 3 include:

- high reliability of calculated forecasts for the removal of unfavorable groundwater backwaters;
- the smallest dimensions of filtration losses of water from the canal;
- guaranteed operation of the system in the event of groundwater backwater during its reliable operation;
- the admissibility of arbitrary operation of the water level in the channel.

The disadvantages of option 3 are:

- the greatest of all the compared options, the complexity of work associated with the installation of associated drainage on both sides of the canal with an increase in the volume of earthworks;
- susceptibility to corrosion and failure before the occurrence of groundwater backwaters of the system of metal outlets of part of the drained water into the canal;
- the need for some operating costs for the inspection, maintenance and repair of drained water outlets equipped with special valves;
- the highest cost of measures to prevent the harmful effects of groundwater backwaters that occur in various sections of the canal 5-15 years after the start of its operation.

The advantages of option 4 include:

- relatively low labor intensity of the work, and perhaps even the smallest of all the options considered;
- lack of special devices for diversion and discharge of drained waters;
- the smallest size of filtration losses of water from the caala ;
- the lowest cost of activities during construction.

The disadvantages of option 4 are:

- the need for constant monitoring of the state of the groundwater level in order to establish the timing of the opening of drainage holes in the canal lining;
- preparation and storage of a sufficiently large number of filter cups of a special design;
- the need for appropriate periods of drilling holes in the cladding to remove unfavorable groundwater backwater and install filter cups;
- the need for additional operating costs for the installation, maintenance and repair of filter cups.

Thus, the main conclusions arising from the foregoing can be formulated as follows. First of all, we note that the considered options for measures to reduce ground pressure are, in principle, competitive. At the same time, according to the sum of the above assessments of positive and negative sides, preference should be given to two constructive solutions, namely options 1 and 4, since they achieve more significant advantages than the rest.

## 5. CONCLUSIONS IT HAS BEEN CONFIRMED

by research that the proposed structures for fastening the slopes of the channel make it possible to exclude the uplift of plates by excessive hydrodynamic pressure at high standing groundwater and a sharp discharge of water in the channel, ensure the reliability and durability of the lining during operation, and reduce filtration losses from the channel at any standing ground level. water.

The developed method for determining the parameters and the proposed design of the slope support are of great interest in the design, construction and operation of canals and underground hydraulic structures.

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