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Effect of subsoil moisture on filtration through a screen defect

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Abstract. The aim of the scientific work is to study the features of filtration under a defect of a polymer screen made of a geomembrane, where the movement of the filtration flow occurs with incomplete saturation of the soil with water. According to the results of experimental studies, local filtration is formed on the filtration tray under the screen defect with incomplete saturation of the soil with water, caused by the action of capillary forces and the presence of trapped air. The article presents the results of studies of a model of a polymer screen with a defect in the form of a slit with a relative width of 0.005 to 0.5. On the basis of studies in a soil flume and experimental pits with film screens, the average moisture content for sandy and loamy soil was established directly under the screen defect. According to the results of the calculations performed, the piezometric pressure along the screen slit significantly decreases with an increase in the permeability of the screen base and reaches negative values at relatively large values of the slit width. The filtration flow through the slit increases with an increase in the permeability of the base soil, and the width of the spreading zone of the filtration flow under the screen decreases. The urgency of solving this problem is due to insufficient study of the influence of moisture saturation of the base soil on filtration through a screen defect.

1. *Introduction*

Filtration through polymer screen damage was studied by a number of researchers, among them: S.V. Solsky and M.G. Lopatina [1], Yu.M. Kosichenko and O.A. Baev [2–6], A.V. Ishchenko [7, 8], M.A. Chernov [9], I.A. Pechenezhskaya [10, 11], J.R. Giroud [12, 13], K. Rowe [14], Touze-Foltz [15], G.R. Koerner [16–18] et alia.

In the work of M.A. Bandurina [19], the software and hardware complex was developed to diagnose the technical condition of water supply facilities of irrigation systems, which provided for the detection of defects in the lining and subsoil base using acoustic and GPR non-destructive testing methods.

In the last 10–20 years geosynthetic materials [20] have been increasingly utilized in small hydraulic engineering. They can successfully be used for environmental facilities industrial and household waste storage facilities, as well as canals and water bodies.

The use of waterproof geosynthetic materials on irrigation canals is considered promising, where losses reach 30 %, of which 80–90 % are due to filtration [4]. Currently, the efficiency of most irrigation canals is 0.75–0.80, and if seepage-control lining used with geosynthetic materials, the efficiency will reach 0.97–0.98 [4]. Thus, the seepage-control effect of geosynthetic materials on the canals can be around 20–30 %.

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Although geosynthetic linings are highly reliable, they can still have various damages during construction and operation. As a result, a significant amount of research was performed on the water permeability of polymer screens and lining.

Among these works, an article by the authors [5] is worth mentioning, where various methods for calculating the water permeability of polymer screens are considered: experimental, theoretical and experimental-theoretical. Based on the results of the theoretical formulas, it was established that calculations according to Yu.M. Kosichenko and V.H. Zhilenkov gives close values of specific filtration flow through a continuous slot, and according to the formula of V.N. Nedriga, a significant discrepancy of up to 30–50 % was obtained. When analyzing the filtration flow through a slot in a polymer geomembrane by a number of design dependencies, including J.P. Giroud [12], the results are consistent with each other. However, using the R.K. Rowe formula [14] a discrepancy of up to 75 % appears, which can be explained by their rather complex appearance and the need to use special functions.

Another article by the authors [6] investigates the problem of water permeability of a polymer screen from a geomembrane through a system of slots. The solution to this problem was obtained using the method of conformal mapping and speed travel time curve. Here a comparison with J.P. Giroud's formula gives a large discrepancy between 67 % and 128 % depending on the slot width, which is fundamentally different from other formulas as it uses the law of non-linear filtration and empirical coefficients from field studies.

In the works of foreign authors [13, 15] an empirical equation for calculating the velocity of fluid flow through the composite lining due to defects in the geomembrane was obtained. Three types of damage were considered (circular, infinite length damage and cracked defects) and three types of contact (“excellent”, “good” and “bad”).

The forecast of the longevity of geotextiles and geomembranes is discussed in the article [16]. The half-life of unexposed (or coated) high density polyethylene (HDPE) geomembranes with a thickness of 1.5 mm (with a value of 50 % retained strength and elongation) was approximately 450 years. Laboratory tests were conducted over a period of 12 years. The situation is completely different for open geosynthetic materials. They are directly affected by ultraviolet radiation and higher temperatures, which shorten their lifetime. The ratio of unexposed to exposed samples for the HDPE geomembrane is 7 units. Research results for geomembranes range from 47 to 97 years, which took 12 years of laboratory testing to achieve. These results are considered to be the most interesting and were first obtained by the authors.

However, the data given on the durability of closed geomembranes in [17] is considerably overestimated. Thus, according to our calculations [4] (based on the formula derived from the Rice distribution), the predicted (calculated) service life of geomembranes with protective lining made of rubblework is 130 years. As for open geomembranes without protective lining, according to our field observations, their service life may not exceed 25 years. “Similarly”, “Texpolimer” guarantees the service life of HDPE and LDPE geomembranes at least 25 years. Carpi's field and laboratory research [21] also showed that permanent open geomembranes have a service life of over 50 years, and for geomembranes under water, 200 years. The Federal Institute for Materials Research in Berlin (BAM) conducted a thorough 365-day life cycle test of bentonitic mats [22]. The test results were then extrapolated using the Arrhenius method, which established a period of 200 years for the use of bentonite coverings, confirming the data previously considered.

Overseas, there is also considerable focus on the application and research of geosynthetic materials (geomembranes) and bentonitic mats (GCL). The article [23] discusses laboratory studies of the capacity of conventional and multi-component geocomposites for five different bentonite clay inserts and a number of different geomembranes (GM). The impact of a 4 mm round defect in the lining of a multi-component geosynthetic material (GCL, geosynthetic clay liner) directly below a 10 mm diameter slot in the geomembrane was investigated.

The canal lining is used to reduce water losses during irrigation [24]. The use of geosynthetic materials, which have been widely used in construction areas, in combination with concrete or as a separate material by replacing concrete with geosynthetic material, is the most economical method for canal lining.

The influence of a defect in the geomembrane on water filtration in groundwater dams and methods of filtering control are discussed in this paper [25]. Defects in the geomembrane can lead to potential hazards for the dam with the geomembrane on its surface, so three-dimensional saturated infiltration fields with different sizes of defects in the geomembrane were simulated using the finite element method. The process of filtering through faulty geomembranes was simulated using methods of removing faulty elements and increasing permeability. The results show that seepage caused by defects have a significant impact on the local seepage field near the defects and have little effect on other parts of the dam.

A general scheme for calculating the flow rate of a liquid through a composite lining (geomembrane + subsoil base) with slots is presented in [14]. Solutions obtained for a round slots and a damaged fold can be used to interpret field conditions and analyse data on the field seepage. A number of existing solutions have been obtained from the general solution as individual cases.

The durability of open geomembrane lining is discussed in the article [17, 18]. Factors such as ultraviolet radiation, elevated temperatures and oxygen exposure reduce the life of the geomembrane. Ultraviolet fluorescent lamps were used in the studies, where five different geomembranes were evaluated. Each material was examined at temperatures ranging from 60 to 80 °C, with a 50 % reduction in strength and elongation. The results obtained by the authors are similar [17].

It is known that if all base soil pores are completely saturated with water, the filtration flow will be maximised. In case of incomplete soil saturation of the base (according to S.F. Averyanov) the movement of liquids takes place in a three-phase system: soil-liquid-gas skeleton. Water permeability in this case will depend, in addition to the factors determining the filtration coefficient, also on the humidity or saturation degree (ω).

Liquid movement when the ground is not fully saturated is carried out by a partially filled capillary at the walls, so if there is air and water in the ground pores, water will adjoin the skeleton directly and air will be inside the water. Given these circumstances, S.F. Averyanov obtained the following relationship between the filtration coefficient at partial saturation and the filtration coefficient at full saturation as follows:

$$K_\omega = K \cdot \left(\frac{\omega - \omega_o}{m - \omega_1} \right)^{3.5} \quad (1.1)$$

where K_ω and K are water permeability coefficients, respectively, at partial and full saturation, m/day; ω is humidity in the experiments, at which the value of K_ω was determined, %; m is humidity corresponding to full porosity, in % of the mass of dry soil, %; ω_1 is humidity at which the permeability was highest in the experiments, %; ω_o is humidity corresponding to bound water, %.

The dependency analysis (1.1) shows that the bracketed expression will always be less than one and will give an even smaller value when raised to 3.5. Based on the above, the value of the filtration coefficient at partial saturation will almost always be lower than at full saturation (K).

A review of domestic and foreign sources shows that the study of water permeability was carried out mainly only with full saturation of the filtration area. However, in real conditions, when local filtration is observed through screen defects of a small size, it will occur with incomplete water saturation of the pores of the foundation soil. A number of scientists (S.F. Averyanov, P.Ya. Polubarinova-Kochina, D.F. Shulgin and others) have already proved that for some tasks: drip and subsurface irrigation, incomplete moisture saturation during filtration will be very characteristic.

In this regard, it is urgent to solve the problem of incomplete moisture saturation of the base soil when filtering through a defect in the polymer screen. The aim of the study was to study the features of filtration through a defect in a polymer screen in a soil base with incomplete moisture saturation. Research tasks include:

- description of a soil filtration flume with a screen model made of a polymer geomembrane;
- carrying out experimental studies at different reduced width of the screen slit;
- presentation of the experiments carried out on a filtration pan with incomplete water saturation in the soil base;
- consideration of the theoretical problem of incomplete moisture saturation by the source-runoff method;
- comparison of calculations of filtration from a gap of a polymer screen at full and incomplete moisture saturation.

The object of research is a model of a polymer screen with a defect in the form of a gap, the subject of research is the process of filtration through a defect of a polymer screen in a soil base with incomplete moisture saturation.

2. Methods

A soil filtration tray 1.4×2.0×0.47 m was used for the studies. The model of the seepage-control blanket made of a polymer geomembrane with a protective lining was made of a 0.2 mm thick polyethylene stabilised film at a linear scale of 1:5, which corresponds to a life-size 1.0 mm thick polymer geomembrane. Water was supplied from the pressure tank and drained through the side pockets.

At the bottom of the tray, a drainage layer of 20–40 mm crushed stone was laid to drain water into the side pockets. The use of thin polyethylene film on the model created a tight fit of the screen to the base. Medium sand was used for the protective layer.

Fine sand filtration coefficient in the ground base of the screen at full saturation with water is $K = 4.8$ m/day, porosity $n = 39.87\,\%$, humidity corresponding to bound water $\omega_o = 3.7\,\%$. Experiments were carried out for two cases: $\delta_o = 0$ without and with the protective layer $\delta_o = 10$. Screen pressure was $H = 0.2$ m. The given width of the slot in the film screen (m/h) was taken from 0.005 to 0.5.

Ground humidity under the screen slot was recorded by laboratory analysis of samples taken immediately after the experience was stopped once the established filtering process had been achieved. Sampling sites were taken under a screen slot at a depth $h = 0$ and 10 cm.

3. Results and Discussion

The results were obtained on the filtration tray at different relative depths of humidity measurement from the screen $h/H = 0$; 0.5 and at different adduced widths of the slot in the screen $m/h = 0.005$; 0.025; 0.05; 0.25; 0.5 (Table 3.1).

Table 3.1. Results of experimental studies on the soil filtration tray.

Width Screen slots, m/h	$h/H = 0$			$h/H = 0.5$		
	ω_1, %	ω^o	μ	ω_1, %	ω^o	μ
			Without protective layer $(\delta_o/H = 0)$			
0.005	14.31	0.448	0.060	15.34	0.491	0.083
0.025	15.20	0.485	0.080	16.37	0.535	0.112
0.05	15.58	0.501	0.089	19.31	0.659	0.233
0.25	19.74	0.677	0.256	22.10	0.777	0.413
0.5	19.60	0.671	0.255	21.92	0.769	0.400
			With protective layer $(\delta_o/H = 0.5)$			
0.005	14.10	0.439	0.056	15.04	0.479	0.076
0.025	15.00	0.477	0.075	15.90	0.515	0.098
0.05	14.83	0.470	0.070	16.16	0.525	0.105
0.25	19.20	0.654	0.226	21.69	0.759	0.382
0.5	19.50	0.669	0.242	20.43	0.706	0.295

The following designations were used in the calculations (except for the above-mentioned): ω is ground humidity measured in the experiment, %; ω_1 is water-saturated ground humidity of the screen base, taking into account a certain amount of pressurized air, %; $\omega^o = (\omega - \omega_o)/(\omega_1 - \omega_o)$ is relative ground humidity in the experiment; $\mu = K_\omega / K_{\omega_1}$ is ground saturation coefficient of the base; water permeability coefficient of the base ground at humidity ω_1 was assumed to be equal to $K_{\omega_1} = 1.10$ m/day; water permeability coefficient at full saturation of the ground pores K_ω was determined using S.F. Averyanov's formula (1).

From the analysis of the data given in Table 3.1, it can be concluded that the humidity and permeability of the base soil under a screen slot depends on the opening width. As the size of the gap increases, moisture and ground permeability increase [26, 27]. This is because as the width of the slot increases, the flow of water filtered through the slot into the sub-screen base increases, thereby increasing the saturation of the area and thus its permeability. With a protective layer of screen, the permeability of the soil under the screen slot is reduced compared to the case without a protective layer. In all the cases studied, the saturation coefficient μ in relation to the maximum possible ground permeability in the tray near the slot varies from 0.06 to 0.4 and relative humidity ω^{o} from 0.44 to 0.77.

The average value of relative humidity at practically possible slots $(m/h < 0.05)$ for sandy ground conditions of the screen model base was 0.45–0.55.

If there are loamy soils at the base of polymer screens, we will determine the relative humidity using the results of "VNIIGIM" (All-Russian Scientific Research Institute of Hydraulic Engineering And Melioration named after A.N. Kostyakov) field observations on open pits. According to these experiments, the maximum humidity of loamy soil under the film screen was 18–22 %; the average humidity at full saturation of the soil was 41 %; and the natural humidity was 5–7 %. According to the provided data, the average relative humidity of loamy soil, taking into account natural humidity, can be assumed to be between 0.35 and 0.45.

On the basis of the experiments carried out, it can be noted that when filtering through a slot in the polymer screen, the following proportions will generally be observed for practically possible sizes $(m/h < 0.05)$ in the sub-screen base:

$$\omega_{o} < \omega < \omega_{1} \leq n \ \text{ or } \ K_{\omega} < K_{\omega_{1}} < K_{\omega}, \tag{3.1}$$

i. e. accordingly, the soil humidity and water permeability the coefficient of the filtration zone under the screen slot will be lower than the soil porosity and filtration coefficient at full saturation.

Thus, as a result of experiments on the physical model, it was established that under the slot of the film screen, the movement of water takes place with incomplete water saturation caused by capillary forces and the presence of entrapped air in the ground. The movement of the filtration flow through the small damage is usually accompanied by the formation of two zones in the sub-screen base. The full saturation zone directly at the screen damage and the partial saturation zone surrounding it. Therefore, in order to clarify the calculations of filtration through screen damage, it would be advisable to take into account the incomplete soil saturation of the filtration zone at the sub-screen base.

Let us further consider theoretical solutions using the source-sink method as a justification for experimental models of incomplete water saturation of the base soil with the polymer screen damage [26, 27]. Replacing the slots with linear ones and the slots in the polymer screen with point sources and using a model of water transfer in an unsaturated environment, we will show the possibility of taking into account the incomplete saturation of the filtration area in the calculations of the polymer screen water permeability. For this purpose, we will use theoretical models [27] for non-stationary water transfer tasks in drip and inland irrigation. We assume that the sources are on the surface of the base where the screen is damaged, there is no evaporation from the surface of the base, and the initial moisture distribution in the base soil thickness is homogeneous and equal $\omega(x, y, z, o) = \omega_{o} = \text{const}$.

Then the task of distribution of moisture in the sub-screen base through N sources (screen damage) by the intensity $q(t) = (i = 1, N)$ and located in the plane OXY coinciding with the surface of the screen will be reduced to the next marginal non-stationary task of moisture transfer [26] in the area $\Omega = \{(x, y, z, t); z \geq 0; -\infty < x, y < \infty, t \geq 0\}$:

$$\frac{\partial \omega}{\partial t} = \text{div}\left[D(\omega)\text{grad}\omega\right] - \frac{\partial K(\omega)}{\partial Z} + \sum_{i=1}^{N} q_{i}(t) \cdot \delta(x - x_{i}) \cdot \delta(y - y_{i}) \cdot \delta(Z). \tag{3.2}$$

Under initial and boundary conditions:

$$\omega(x, y, z, o) = \omega_{o}; \ \omega(x, y, z, o) = \omega_{o}(Z_{o} \to \infty), \tag{3.3}$$

where $\omega(x, y, z, o)$ is volume humidity; $D(\omega) = K(\omega)\dfrac{d\Psi(\omega)}{d(\omega)}$ is capillary diffusion coefficient; $\Psi(\omega) = \rho/\gamma < 0$ is capillary potential; $K(\omega)$ is moisture conductivity coefficient; δ is dirac delta function.

The last term in equation (3.2) characterises the presence in the plane OXY N of intensity sources $q_{i}(t)$; $x_{i}, y_{i}, z = 0$ are coordinates of the i-th source; the axis OZ is directed vertically downwards.

The solution of equation (3.3) of a nonsteady problem for a semi-limited region in the presence of a point source, obtained by S.N. Novoselsky [26], is generally presented:

$$\theta(\bar{x},\bar{y},\bar{z},\tau)=\frac{e^{\bar{Z}}}{\sqrt{\pi}}\int_0^{\tau} q_1\left(\frac{\tau-\zeta}{\alpha_o}\right)\cdot\zeta^{-3/2}\cdot\exp\left(-\zeta-\frac{\bar{r}^2}{4\zeta}\right)d\zeta- \\ -e^{-2\bar{Z}}\int_0^{\tau}\left(\frac{\tau-\zeta}{\alpha_o}\right)\cdot e^{-\frac{\bar{R}^2}{4\zeta}}\cdot\operatorname{erfc}\left(\frac{\bar{Z}}{2\sqrt{\zeta}}+\sqrt{\zeta}\right)\cdot\frac{d\zeta}{\zeta}, \tag{3.4}$$

where $\bar{x}=\beta x$; $\bar{y}=\beta y$; $\bar{z}=\beta z$; $\beta=0.5\cdot K_1=0.5\cdot\alpha\cdot n$; $\alpha=0.02-0.1$ cm^{-1}; $n=3-5$; $\tau=\frac{\bar{D}k_1^2}{4}t=\alpha_o t$; $\theta=\frac{4}{\beta q^*}$; $\bar{R}^2=\bar{x}^2+\bar{y}^2$; $\operatorname{erfc}\rho=1-\operatorname{erf}\rho$; $\operatorname{erf}\rho=\frac{2}{\sqrt{\pi}}\int_0^{\rho}e^{-\mu^2}d\mu$ are probability integral.

In the case of a linear final length source $(\bar{z}=0,\ \bar{x}=0,\ \bar{y}_1\le\bar{y}\le\bar{y}_2)$.

$$\theta(\bar{x},\bar{y},\bar{z},\tau)=\frac{e^{-\bar{Z}}}{\beta}\int_0^{\tau} q_1\left(\frac{\tau-\zeta}{\alpha_o}\right)\cdot(\operatorname{erfc}\rho_1-\operatorname{erc}\rho_2)\cdot \\ \cdot\exp\left(-\zeta-\frac{\bar{x}^2+\bar{Z}^2}{4\zeta}\right)d\zeta-e^{-2\bar{Z}}\int_0^{\tau} q_1\left(\frac{\tau-\zeta}{\alpha_o}\right)\cdot \\ \cdot(\operatorname{erfc}\rho_1-\operatorname{erfc}\rho_2)\cdot\exp\left(\frac{\bar{x}^2}{4\zeta}\right)\cdot\operatorname{erfc}\left(\frac{\bar{Z}}{2\sqrt{\zeta}}+\sqrt{\zeta}\right)\cdot\frac{d\zeta}{\zeta}, \tag{3.5}$$

where $\rho_{1.2}=\frac{\bar{y}_{1.2}-\bar{y}}{2\sqrt{\zeta}}$.

When calculating the dependencies (3.3)–(3.6), the average value of the capillary diffusion coefficient $D(\omega)$ shall be set using the dependencies of capillary potential $\Psi(\omega)$ proposed by A.I. Golovanov. Based on a numerical calculation, it is possible to determine the expenditure through screen damage (sources) q_1 at any point in time.

For an approximate assessment of filtration seepage through polymer screen damage, it is sufficient to consider the filtration coefficient at partial saturation k_ω instead of the underside of the screen at full saturation k_2 in the previously obtained analytical dependencies:

$$q_{s\omega}=\frac{\pi k_\omega(h_1+H_c)}{Arsh(1/\sqrt{\alpha-1})}; \tag{3.6}$$

$$B_\omega=\frac{2q_{s\omega}}{\pi^2 k_\omega}\cdot\int_0^1\frac{Arch\,(1/\sqrt{\zeta})}{\sqrt{(1-\zeta)(\zeta-\alpha)}}\cdot d\zeta+m; \tag{3.7}$$

$$h_{1\omega}=\frac{\sigma_\omega(h_0+\delta_o)\cdot Arsh(1/\sqrt{\alpha-1})-H_c\cdot\ln(16\delta_o/\pi m)}{\sigma_\omega\cdot Arsh(1/\sqrt{\alpha-1})+\ln(16\delta_o/\pi m)}; \tag{3.8}$$

$$B_\infty=q_{s\omega}/K_\omega; \tag{3.9}$$

where $q_{s\omega}$ is specific flow rate of filtration through the slot of the polymer screen taking into account the filtration coefficient at partial saturation, m^2/day; B_ω is filtration flow spread width under the screen, m; $h_{1\omega}$ is piezometric pressure in the slot taking into account partial saturation, m; $\sigma_\omega=k_1/K_\omega$ is ratio of the filtration coefficients of the protective layer and the underlying base; H_c is capillary vacuum of the base soil, m; α is a parameter determined from the equation of type $\bar{m}=m/(h_1+H_c)=F_1(\alpha)$ using a special table [2]; m is polymer screen slot width, m; h_0 is water depth in the canal (reservoir), m; δ_o is thickness of the protective layer of the screen, m.

On the basis of the experiments [5] and available field research data on pilot pits and film screens [2], the average humidity for sandy ground directly under the screen damage shall be set within the limits $\omega^o = 0.45 - 0.55$, and for loamy ground - within the limits $\omega^o = 0.35 - 0.45$.

As an example, filtration calculations from a slot in a polymer screen with a protective coating were performed with the following input data: $h_0 = 5.0$ m; $\delta_o = 0.5$ m; $k_1 = 0.1$ m/day for the protective ground layer; $k_2 = 1.0$ m/day for the underlying substrate; $H_c = 0.3$ m. In addition, calculations were made taking into account the incomplete saturation of soil at $\omega^o = 0.5$ in the filtration zone under the polymer screen. The calculation scheme is shown in Fig. 3.1, and the results of the dependencies (3.6)–(3.9) calculations for the different slot widths m are shown in Table 3.2.

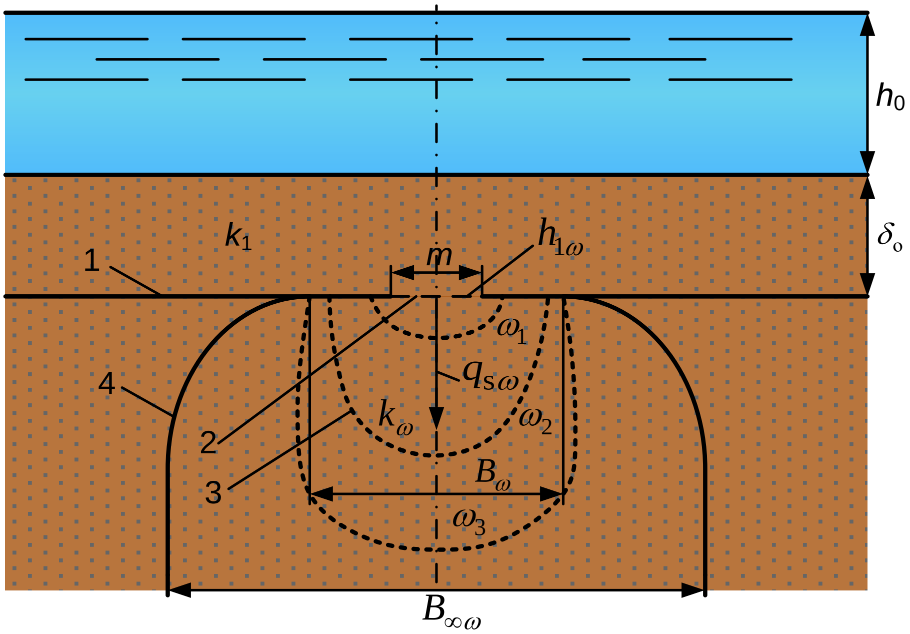

Figure 3.1. Calculation scheme of filtration through the slot of the screen from the geomembrane taking into account the incomplete saturation of the base soil under the screen: 1 – the screen from the geomembrane; 2 – the slot in the screen; 3 – the contours of different ground humidity of the base soil under the slot in the screen ω_1, ω_2, ω_3; 4 – the zone of filtration flow spreading.

Table 3.2. The results of the calculation of filtration from a polymer screen slot with a considered complete and incomplete base saturation.

m/h,	h_1, m	$h_{1.\omega 1}$, m	q_s, m²/day	$q_{s\omega}$, m²/day	B, m	B_ω, m	B_∞, m	$B_{\infty\omega}$, m
0.005	2.27 0.0615	4.98	0.129 0.218	0.0193	0.619 0.104	1.13	1.29 0.218	2.37
0.025	2.30 0.0388	5.00	0.161 0.275	0.0243	0.772 0.131	1.36	1.61 0.275	2.83
0.005	2.32 0.0187	5.01	0.180 0.311	0.0275	0.862 0.151	1.53	1.80 0.311	3.17
0.25	2.37 –0.0346	5.04	0.250 0.422	0.0373	1.195 0.213	1.98	2.50 0.442	4.19
0.5	2.43 –0.105	5.05	0.298 0.543	0.0480	1.422 0.261	2.36	2.98 0.543	4.98

Note: 1. The numerator shows the values of the calculated parameters at full saturation $k_1 = 0.1$ m/day and the denominator at full saturation $k_2 = 1.0$ m/day.

2. Without fractions, the values of the calculated parameters in case of incomplete saturation at the sub-screen base where $\omega^{\mathrm{o}} = 0.5$; $k_{\omega} = k_2(\omega^{\mathrm{o}})^{3.5} = 0.0884$ m/day.

As can be seen from these calculations, the piezometric pressure along the screen slot (h_1) falls significantly as the permeability of the screen base increases and reaches negative values at relatively large slot widths ($m > 0.01$ m). Apparently, the negative values of piezometric pressure here are related to the phenomenon of capillary suction (vacuum) when the filtration flow moves under the screen slot with incomplete water saturation [32, 33].

Table 2 shows that the filtration flow through the slot increases with both the permeability of the base soil and the size of the slot, while the width of the spreading area of the filtration flow under the screen, in contrast, decreases with increasing permeability. Filtration with full saturation is characterised by a small flow spreading width less than the capillary spreading zone $(B < 2H_{\mathrm{c}})$. This is because there is local filtration underneath the screen slot with incomplete pore saturation and therefore the solid flow zone is narrower than the capillary spreading zone.

At the same time, it should be noted that the filtration flow parameters from the polymer screen slot differ significantly in the case of incomplete saturation of the base soil (the filtration coefficient for incomplete saturation is determined using formula S.F. Averyanov's formula for relative humidity $\omega^{\mathrm{o}} = 0.5$). The pressure along the slot and the width of the spreading area below the screen more than doubled (Fig. 3.2).

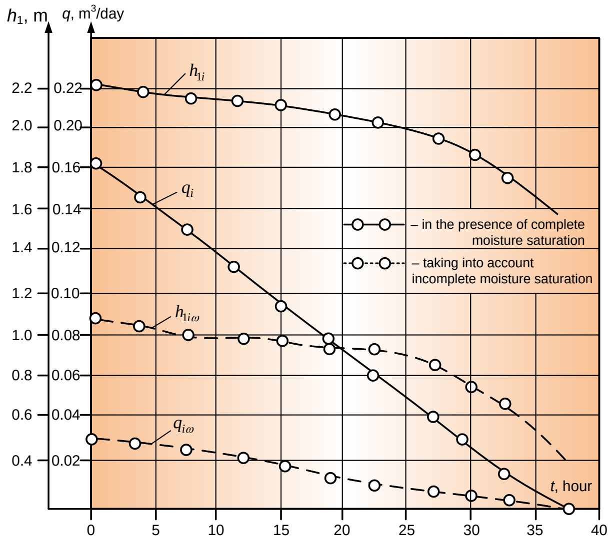

Figure 3.2. Comparative results of calculations of moisture permeability of bentomats in the presence of defects.

The graph (Fig. 3.2) show the change in filtration flow through a single bentonite covering damage at full q_i and partial $q_{i\omega}$ water saturation, as well as the change in pressure at the point of damage at full h_{1i} and partial $h_{1i\omega}$ saturation, respectively. At full saturation, the cost curve drops from maximum to zero at $t = 37.5$ hours, while at partial saturation – it drops slowly. In contrast to flow curves, the pressure h_1 at the fault location changes slowly up to $t = 25$ hour and then drops sharply to some minimum value.

4. Conclusions

1. Studies carried out on a soil filtration tray with a geomembrane screen model and slot damage with a fine sand substrate showed that the filtration flow through the slot moves into the sub-screen substrate with incomplete water saturation caused by capillary forces and the presence of entrapped air. With a protective screen layer, the permeability of the soil under the screen slot in the filter area is reduced compared to the case without a protective screen layer. In all the cases studied, the soil saturation coefficient in relation to the maximum possible soil permeability in the tray near the slot varies from 0.06 to 0.40 and relative humidity from 0.44 to 0.77.

2. Using theoretical solutions, the source-drain method and the unsaturated water transfer model, where slots can be replaced by linear ones and the slots in the polymer screen – by point sources, it is shown how solutions can be obtained for non-stationary water transfer tasks under the screen, which are used in drip and subsoilwater irrigation.

3. Specially performed calculations for the example show that the specific filtration flow from a polymer screen slot at partial saturation $(q_{s\omega})$ decreases compared to full saturation (in the fraction denominator) depending on the width of the slot, the pressure in the slot h_1 increases from 2.27 to 2.43 m, and in the sub-screen base drops from 0.0615 to minus 0.105 m, which is due to the appearance of a vacuum, with the width of the spreading area of the filtration flow directly below the screen B_ω at in infinity $B_{\infty\omega}$ increasing by approximately two times.

4. The results of moisture permeability of bentomat in the presence of defects were also obtained. They show changes in flow rates and pressures at full and incomplete moisture saturation.

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