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Methodology for Determining the Filtration Parameters of Drainage Bedding During Engineering Surveying

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***Abstract*—In recent years we have encountered a big issue - underflooding in large cities and settlements, railroads' and highways' locations. In order to prevent and liquidate the consequences of underflooding during the design of engineering structures, it is necessary to carry out engineering surveying, which will help to obtain parameters of soil filtration (drainage bedding in underflooded areas, etc.). The article presents a methodology for determining the filtration parameters of drainage bedding (the Korchevskaya methodology), which allows to simplify the method of obtaining and processing feed data. In these studies, sand was used as a drainage bedding and the coefficients of filtration, lack of saturation and water loss were determined. This methodology allows obtaining the filtration parameters that are necessary for predictive estimates of underflooding of lands with various purposes and designing engineering structures, when performing elementary experiments, such as pouring water into the studied rocks of different compositions. The developed methodology allows you to automate the calculation using information systems.**

Keywords—underflooding, filtration parameters, drainage bedding, filtration coefficient, lack of saturation.

I. Introduction

Underflooding is one of the most common processes; the consequences can cause emergency situations that negatively affect the environment, leading to the destruction of living and production areas, washing out and collapse of roads.

In the 1940-1960th Professor S.K. Abramov dealt with issues of theory and practice protection against underflooding in industrial and urban constructions. In subsequent years, issues of underflooding and the solution of this problem were actively dealt by A.Zh. Muftakhov, B.M. Degtyarev, V.I. Fedorov, N.P. Kuranov and others [1-2].

The first official regulatory document was the Building Code "Engineering protection of the territory from flooding and underflooding" [3].

In recent years, underflooding in large cities, settlements, and in railroads' and highways' locations has become a big issue.

About 70% of cities in Russia are subjected to underflooding. Underflooding is especially dangerous, since it is of insidious nature and its development provokes the emergence of negative processes and phenomena associated with the activity of water.

In the case of engineering intervention in natural processes during land reclamation, road and urban construction, an anthropogenic impact on the geological, hydrogeological and other natural environments occurs. In this regard, the manifestation of various kinds of processes that negatively affect the ecology and the state of the environment is possible. For example, the accumulation of moisture in the thickness of the soil and the rise in the level of groundwater, will lead to underflooding. This is due to the violation of natural dynamic equilibrium in the water balance of the territory. As a result of the groundwater rise, mass transfer begins between groundwater and substances located in the aeration zone – the process of dissolution, washout, crystallization of salts in soils in the built-up territories and territories of the agro-industrial sector. Therefore, the forecasting and technical feasibility of engineering measures to protect against underflooding are extremely relevant in the design of structures.

In order to prevent and combat the consequences of underflooding during the design of engineering structures, it is necessary to carry out engineering surveying, which will help to obtain parameters of soil filtration (drainage bedding in underflooded areas, etc.)

At the design stage, pilot filtration works are carried out, which can be carried out both in aquifers and non-aquifers. Filtration coefficients, conductivity, piezoconductivity, water loss, saturation deficit, elastic capacity are determined in aquifers; active porosity is determined when using indicators; in non-aquifers we additionally determined the height of the capillary vacuum (rise) and active porosity (without the use of indicators).

All further work of structures and engineering underflood protection devices depends on the quality of determining the filtration parameters of soils. The reasons for the low accuracy of the feed data can often be associated with methods for their determination [4-5].

II. Methods

Since the standard methods for determining the filtration characteristics of draining beddings during engineering surveying are quite laborious, a new method was developed and proposed for determining the filtration parameters of draining beddings (Korchevskaya methodology). This methodology allows us to simplify the method of obtaining filtration parameters and their processing (Fig. 1).

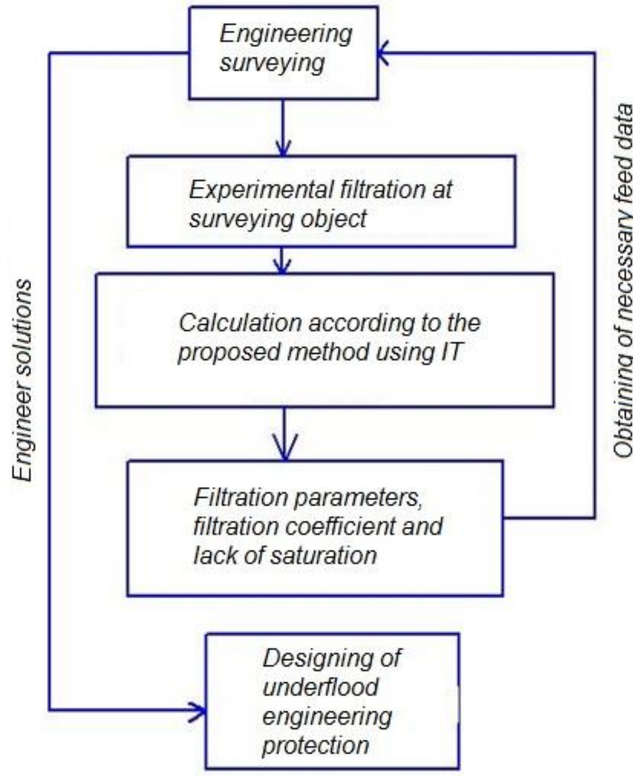

Fig. 1. The sequence of performance in the proposed method

Draining bedding is a layer of bulk soil, created in order to lower the groundwater level and increase planning marks in this area. Filling is done in areas with a high level of groundwater, as well as during construction in places prone to flooding.

Crushed stone of 3-20 mm fractions, preferably of a cubic or spherical shape with a content of clay particles of not more than 1.5% by weight or sand, is used as material for backfilling. Sand – an incoherent mineral soil, the mass of particles less than 2 mm in size is more than 50% [6].

Various methods that can possibly find the coefficients of filtration, lack of saturation and water loss (desired parameters) of draining bedding, were examined in this study:

- method of plane-parallel loading;
- radial loading method.

The use of these methods depends on the task and the type of projected object. The method of plane-parallel loading is an experiment of pouring water into a trench, and the radial loading method is an experiment of pouring water into a pit.

In order to determine a reliable result for each method, three calculation methods were considered:

- determination of filtration parameters according to simplified formulas;
- determination of filtration parameters without capillarity;
- determination of filtration parameters with capillarity.

The calculation formulas of these methods are presented in table 1.

TABLE I. FORMULAS FOR CALCULATING FILTRATION PARAMETERS (ANALYTICAL DEPENDENCIES)

Calculation Method	**Methods for determining filtration parameters**
	Plane-parallel loading
Simplified formulas	$\begin{cases} t_{3/4} = \dfrac{B^2}{9H_0 \cdot k \cdot \mu} \\ t_{1/2} = \dfrac{B^2}{k \cdot H_0 \cdot \mu} \end{cases}$
Without capillarity	under pressure $t = \dfrac{H_t B^2}{4\mu k M^2}\left[1 - \dfrac{H_0}{H_t}\left(1 - \ln\dfrac{H_0}{H_t}\right)\right]$ without pressure $t = \dfrac{B^2}{\mu k H_t}\left[1 - \dfrac{H_0}{H_t}\left(1 - \ln\dfrac{H_0}{H_t}\right)\right]$
With capillarity	under pressure $t = \dfrac{H_t B^2}{4\mu k M^2}\left\{1 - \dfrac{H_0}{H_t}\left[1 - \left(1 + \dfrac{h_k}{H_0} - \dfrac{M}{2H_0}\right)\ln\dfrac{H_0 + h_k - M/2}{H_t + h_k - M/2}\right]\right\}$ without pressure $t = \dfrac{B^2}{\mu k H_t}\left\{1 - \dfrac{H_0}{H_t}\left[1 - \left(1 + \dfrac{h_k}{H_0} - \dfrac{H_t}{4H_0}\right)\ln\dfrac{H_0 + h_k - H_t/4}{H_t + h_k - H_t/4}\right]\right\}$
	Radial loading
Simplified formulas	$\begin{cases} t_{3/4} = \dfrac{R_0^2 \cdot \ln\left(-\dfrac{1}{2} + \sqrt{\dfrac{1}{\mu} + \dfrac{9}{4}}\right)}{3H_0 \cdot k} \\ t_{1/2} = \dfrac{R_0^2 \cdot \ln\left(-\dfrac{1}{2} + \sqrt{\dfrac{9}{4} + \dfrac{3}{\mu}}\right)}{k \cdot H_0} \end{cases}$
Without capillarity	under pressure $t = \dfrac{\ln(\dfrac{H_o}{H_t}) R_o^2 \ln(\sqrt{1 + \dfrac{H_o - H_t}{\mu M}})}{2kM}$ without pressure $t = \dfrac{R_o^2 \ln(-\dfrac{1}{2} + \sqrt{\dfrac{9}{4} + \dfrac{3(H_o/H_t - 1)}{\mu}}) \ln(\dfrac{H_o}{H_t})}{kH_t}$
With capillarity	under pressure $t = \dfrac{R_o^2 \ln(\dfrac{H_o + h_k - M/2}{H_t + h_k - M/2}) \ln(\sqrt{1 + \dfrac{H_o - H_t}{\mu M}})}{2kM}$ without pressure $t = \dfrac{R_o^2 \ln(-\dfrac{1}{2} + \sqrt{\dfrac{9}{4} + \dfrac{3(H_o/H_t - 1)}{\mu}}) \ln(\dfrac{H_o + h_k - H_t/4}{H_t + h_k - H_t/4})}{kH_t}$

When calculating according to the above dependences, the following feed data are required: R_o – pit radius, in meters; B – width of the trench, in meters; H_o, H_t – initial and final pressure, in meters; t – time during which the water level in the pit or trench changes, in seconds.

Table 1 presents the calculation methods with and without capillarity. Capillary rise is the property of soils to raise and hold moisture at a known height in an amount exceeding the maximum moisture capacity. To take this indicator into account, the capillary rise height was determined, which is necessary for calculating the proposed analytical dependencies.

The height of the capillary rise is determined by the capillary method using the Timer macro program based on the MSExcel spreadsheet.

There are various methods of filtration modeling: the method of viscosity analogy consists in passing a viscous fluid into the gap between two parallel plates (Gil Shaw, 1891; E.A. Zamarin, 1931; V.I. Aravin, 1938); modeling of filtration in a slotted tray (P.Ya. Polubarinova-Kochina, 1952; Barenblatt, 1952; L.A. Galin, Z.F. Karpycheva and A.R. Shkirich, 1960; T.S. Karanfilov, 1959; V. A. Ionat, 1962, etc.); modeling on continuous electrical models (Electrohydrodynamic analogy method) (N.N. Pavlovsky, 1922; V.I. Davidovich, 1932; S.M. Proskurnikova, 1938; V.I. Aravin and S.N. Numerov, 1948, 1953, 1955; monograph by N.I. Druzhinin, 1956 and others); modeling on grid integrators (hydraulic and electric) (V.S. Lukyanova and M.A. Veviorovsky, 1960; G.N. Kamensky, I.K. Gavich, N.A. Myasnikova, S.M. Semenova, 1960; V.I. Aravina, 1963; N.A. Myasnikova, 1964 and others) [6-7]

To obtain the feed data, it is necessary to conduct an experiment (modeling) on pouring water into a trench or pit (Fig. 2, 3). As a result of measurements and calculations, indicators such as filtration coefficient (k m / day) and lack of saturation (water loss) (μ).

The filtration coefficient (k m / day) is the filtration rate with a pressure gradient equal to one; movement of free-gravity water in soils in various directions. Lack of saturation μ – is the amount of liquid that the soil can absorb (drainage bedding) when saturated with water [8].

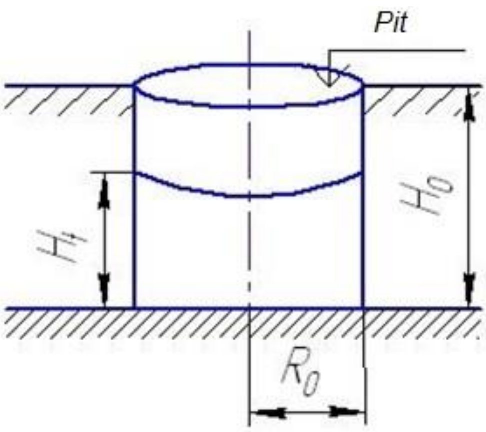

Fig. 2. Scheme of radial loading

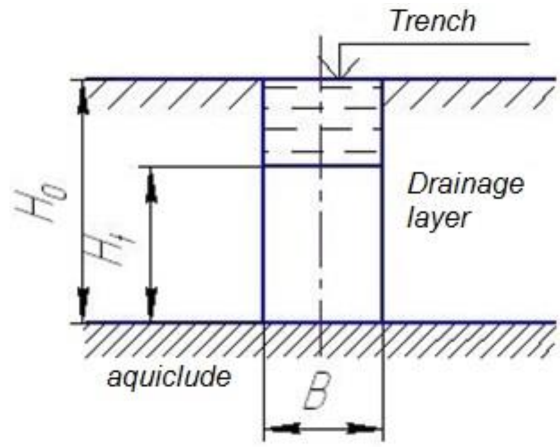

Fig. 3. Scheme of water filtration in the trench

III. Results

To verify the proposed methodology and the reliability of the data on it, a series of experiments were carried out for each of the calculation methods, and the results were analyzed. Since sand is mainly used as a bedding material in construction, experiments were carried out on two sand samples with different particle size distributions. Results, obtained during this study with the proposed methodology, are presented in table 2. The results were obtained using information technology (software package MathCAD).

To verify the reliability of the results, the studied parameters were compared with the data obtained by the “Kamensky tube” technique [8].

TABLE I. Calculation results of filtration parameters according to the proposed method

Calculation Method	Plane-parallel loading			
	Sample 1		*Sample 2*	
	k, at 10^{0}C m/day	***μ***	***k, at 10^{0}C m/day***	***μ***
Simplified formulas	27.3	0.31	17.6	0.328
Without capillarity	18.27	0.31	11.12	0.33
With capillarity	4.75	0.31	3.43	0.33
Kamensky tube technique	4.74	-	3.4	-
	Radial loading			
	Sample 1		*Sample 2*	
	k, at 10^{0}C m/day	***μ***	***k, at 10^{0}C m/day***	***μ***
Simplified formulas	17.3	0.319	9.95	0.328
Without capillarity	6.9	0.319	11.5	0.328
With capillarity	19.8	0.319	2.1	0.328
Kamensky tube technique	19.2	-	2.8	-

Note: the table shows the average data for 30 experiments

A comparative characteristic of the calculating results of the filtration coefficient for plane-parallel and radial loading is shown in Figures 4 and 5.

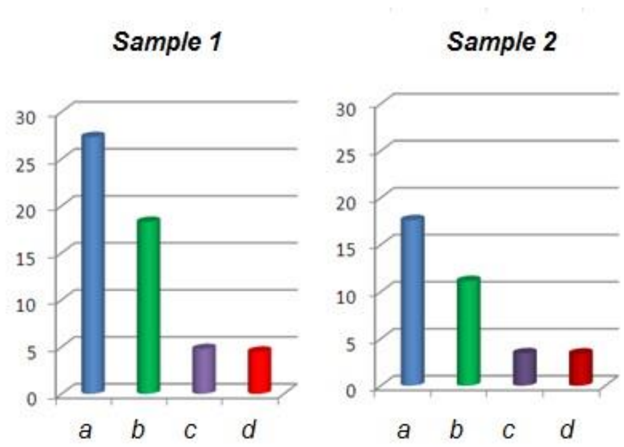

Fig. 4. Comparative characteristics of the results of calculating the filtration coefficient for plane-parallel loading: a - according to simplified formulas; b - excluding capillarity; c - including capillarity; d - the "Kamensky tube" technique

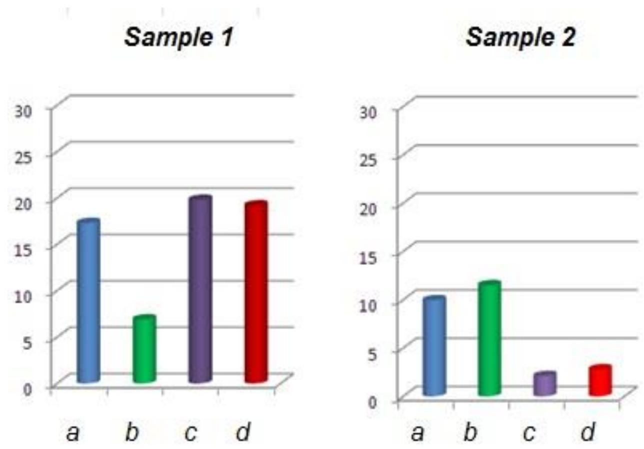

Fig. 5. Comparative characteristics of the results of calculating the filtration coefficient for radial loading: a - according to simplified formulas; b - excluding capillarity; c - including capillarity; d - the "Kamensky tube" technique

According to the values given in table 2 and figures 4 and 5, we can conclude that the calculation according to simplified formulas and excluding capillarity gives overestimated results, and the calculation including capillarity is as close as possible to the calculated data according to the "Kamensky tube" technique, which are taken as reference [8].

The smallest percentage of data discrepancy during plane-parallel and radial filtration, including capillarity for the studied sand samples, is from 0.00% to 0.02%, respectively, and the largest – from 6.05% to 7.88%, which is within the margin of error.

As a result of the calculations, we can conclude that the obtained approximate values of the sand filtration parameters are determined with an error of about 1%-8%.

IV. CONCLUSION

Due to simple and uncomplicated experiments in the form of modeling the loading of water into drainage bedding, the proposed calculation methodology makes it possible to obtain the filtration characteristics needed for predictive estimates of underflooding of lands of various purposes and the design of engineering structures.

The developed methodology for determining the filtration parameters of bedding allows you to automate the calculation using information technologies [9-10].

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