Expanded uncertainty estimation methodology in determining the sandy soils filtration coefficient

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Abstract. The combined standard uncertainty estimation methodology in determining the sandy soils filtration coefficient has been developed. The laboratory researches were carried out which resulted in filtration coefficient determination and combined uncertainty estimation obtaining.

Key-words: filtration coefficient, combined standard uncertainty, standard uncertainty, error, soil

1. Introduction

The metrology community of Russia is currently moving from the measurement results error calculation to the uncertainty estimation which is demonstrated by the standard [1]. The authors of such papers as [2, 3, 4] speak of the «error» and «uncertainty» concepts difference and emphasize the measurement uncertainty significance as a central concept in ensuring the measurement results accuracy. At the moment, many uncertainty estimation methodologies in various fields of science [6, 7, 8] have been developed abroad on the basis of [5]. Uncertainty estimation is important not only for the measuring instruments verification, instruments and auxiliary apparatuses qualification but also in conducting various physical characteristics laboratory studies.

2. Problem statement

Due to the development of new oil and gas fields located in adverse climatic and geological conditions characterized by the swelling and collapsible soils presence, the water-saturated soil foundations settlements rate correct prediction problem remains particularly relevant. This could be explained by the foundation soil mechanical properties changing at the humidity value variation [9, 10, 11] as well as by the soil consolidation, that is foundation soil compaction by means of water squeezing out of the pore space. Consolidation rate characterizing its dynamics depends on the filtration coefficient determining soil permeability. The consolidation process completion is followed by the foundation soil settlements stabilization.

On the basis of the above, the investigated soil filtration coefficient is necessary to be defined and the measurement results uncertainty estimation methodology is required to be developed.

3. Theory

In accordance with the requirements [12] for the filtration coefficient defining, three tests of the investigated soil in the device of Governmental Scientific Research Institute for Roads are required to...
be carried out. The test consists in defining the water level falling time in the piezometer from 0 to 50 mm when water flows through the filtration tube perforated bottom into which the prepared soil under study is placed. The medium sized sandy soil of the Irtysh River floodplain was chosen for the study. The sandy soil filtration coefficient $K_f^{10}$ m/day reduced to the filtration conditions at the temperature of 10 °C is calculated by the formula:

$$K_f^{10} = \frac{h}{t} \cdot \varphi \left( \frac{S}{H_0} \right) \cdot \frac{864}{T},$$  

(1)

Where $h$ is the soil sample height in the tube, cm; $t$ is the water level falling time, s; $S$ is the observed water level falling counted from the initial level in piezometer, cm; $H_0$ is the initial pressure, cm; $\varphi(S/H_0)$ is the dimensionless coefficient defined according to [12, annex 4]; $T$ is the correction for reducing the filtration coefficient value to the water filtration conditions at the temperature of 10 °C calculated by the formula: $T = 0.7 + 0.03 \cdot T_f$; $T_f$ – the actual water temperature when testing, °C; 864 is the conversion coefficient (from cm/s in m/day).

The filtration coefficient defining results are represented in table 1.

When calculating the filtration coefficient, the mercury thermometer with the accuracy of ± 0.5 °C, stopwatch with the accuracy of 10 minutes ± 0.6 s, metal ruler with the accuracy of ± 0.15 mm were used.

| Test No | $h$, cm | $S$, cm | $H_0$, cm | $t$, s | $T_f$, °C | $S/H_0$ | $\varphi(S/H_0)$ | $K_f^{10}$, m/day | $\bar{K}_f^{10}$, m/day |
|--------|--------|--------|-----------|------|----------|--------|-----------------|-------------------|-------------------|
| 1      | 17     | 0.5    | 20        | 109  | 17       | 1.21   | 0.025          | 0.025             | 2.78              |
| 2      | 17     | 1.0    | 20        | 214  | 17       | 1.21   | 0.050          | 0.051             | 2.89              |
| 3      | 17     | 1.5    | 20        | 323  | 17       | 1.21   | 0.075          | 0.078             | 2.93              |

The «combined standard uncertainty» concept representing the positive square root of the total dispersion obtained by the formula below is used to describe the indirect measurements [1]:

$$u_x^2 = \sum_{i=1}^{N} \left( \frac{\partial f}{\partial x_i} \right)^2 \cdot u^2(x_i),$$  

(2)

where $f$ is the function under consideration (1); $u(x_i)$ is the input variable standard uncertainty estimated by A or B type

4. Results

To define the input variables partial differentials, the dependence type is determined as follows: all points from [12, Appendix 4] are plotted on the chart and approximated (figure 1). The obtained dependence is exponential:

$$\varphi = 0.0759e^{4.0346(S/H_0)}.$$

(3)
Having plugged the equation (3) into the formula (1), the sandy soil filtration coefficient defining equation will be as follows:

\[ K_f^{10} = \frac{65.5776 \cdot h \cdot e^{4.0346(S/H_0)}}{t \cdot T}. \] (4)

The partial derivatives of \( h, t, T, (S / H_0) \) are calculated correspondingly:

\[ \frac{\partial K_f^{10}}{\partial h} = \frac{65.5776 \cdot e^{4.0346(S/H_0)}}{t \cdot T}, \] (5)

\[ \frac{\partial K_f^{10}}{\partial t} = -\frac{65.5776 \cdot h \cdot e^{4.0346(S/H_0)}}{t \cdot T}, \] (6)

\[ \frac{\partial K_f^{10}}{\partial T} = -\frac{65.5776 \cdot h \cdot e^{4.0346(S/H_0)}}{t \cdot T^2}, \] (7)

\[ \frac{\partial K_f^{10}}{\partial (S / H_0)} = \frac{264.5794 \cdot h \cdot e^{4.0346(S/H_0)}}{t \cdot T}. \] (8)

On the basis that input variables were not determined as a result of repeated observations, the standard uncertainty is defined by B type [1]. The uniform distribution law theory of the obtained experiment results is accepted as an assumption. Then the standard uncertainty of each input variable is calculated according to the formula:

\[ u_{B_i} = \frac{\Delta x}{\sqrt{3}}, \] (9)

where \( \Delta x \) is the absolute error presented in the technical documentations.

For the variable \( \varphi(S/H_0) \) the absolute error is defined as the maximum values resolution \( \varphi(S/H_0) \) [12, Annex 4].

Hence, the total standard uncertainty by type B is as follows:

\[ u_B [K_f^{10}] = \sqrt{\left( \frac{\partial K_f^{10}}{\partial h} \cdot u_{B_h} \right)^2 + \left( \frac{\partial K_f^{10}}{\partial t} \cdot u_{B_t} \right)^2 + \left( \frac{\partial K_f^{10}}{\partial T} \cdot u_{B_T} \right)^2 + \left( \frac{\partial K_f^{10}}{\partial (S / H_0)} \cdot u_{B_{S/H_0}} \right)^2}. \] (10)
The measurement result of the sandy soil filtration coefficient defining is written in the following form:

\[ K^f_{10} = \bar{K}^f_{10} \pm u_p \left[ K^f_{10} \right], \tag{11} \]

where \( \bar{K}^f_{10} \) is the filtration coefficient mean value:

\[ \bar{K}^f_{10} = \frac{1}{n} \sum_{i=1}^{n} K^f_i, \tag{12} \]

\( n \) is the number of measurements;
\( k \) is the sweep efficiency usually accepted to be 2.

5. Conclusions

Based on the results of laboratory studies presented in table 1, the investigated soil filtration coefficient was defined and the expanded uncertainty estimation was obtained:

\[ K^f_{10} = 2.87 \pm 0.53 \text{ m/day}. \]

The developed methodology allows to estimate the expanded uncertainty for the sandy soil filtration coefficient.

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