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HYDRAULIC DESIGN OF STORMWATER INFILTRATION FACILITY INCLUDING UNCERTAINTIES

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Abstract

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For a design of the volume of the rainfall infiltration facility, the coefficient of infiltration is determined by an infiltration test. The use of the coefficient of infiltration brings certain uncertainties into the solution, arising from different conditions in carrying out the infiltration test and in operating a real infiltration facility. In this study an analysis is carried out of factors that influence the process of infiltration and related uncertainties influencing the determination of the storage volume of the infiltration facility. The effect of the individual factors on the design of the infiltration facility was analyzed using numerical simulations by the software HYDRUS-2D and expressed using partial reliability factors. For their determination the nomographs were set up by extensive numerical computations.

Keywords: infiltration facility, coefficient of infiltration, limit states, reliability factors

INTRODUCTION

The management with rainwater at urbanized territories is traditionally carried out using a system of urban drainage. This method leads to overdimensioning and temporary overloading of sewers. An alternative approach to the integrated control of rainwater prefers the accumulation and infiltration of rainwater at the place of its origin (Grischek *et al.*, 1996), (Watkins, 1997). At the present time, this approach is applied using directives and regulations. In the Czech Republic (CR), the requirements for rainwater infiltration are listed in the Building Code (Česko, 2006) and in the Water Act (Česko, 2001). In the last decades, guidelines and standards have been developed abroad for the design of infiltration facilities (DWA, 2007), (Bloomberg *et al.*, 2012), (DWA, 2005) and (PWD, 2014). In the Czech Republic, these are the Czech technical standards ČSN 75 9010 and TNV 75 9011.

The standard ČSN 75 9010 describes geological and hydrogeological surveys, the result of which is the determination of the coefficient of infiltration. The standard also gives a procedure for designing the volume of infiltration facilities.

The issue of infiltration and flow of water in the unsaturated zone was elaborated in a number of studies which were a basis for compiling relevant software products. The problems of seepage in the saturated and unsaturated zones and their modelling were elaborated for example in the studies (Bear *et al.*, 1992), (Lu *et al.*, 2004), (Šimůnek *et al.*, 2006) and (Šejna *et al.*, 2007). For the use of numerical models it is necessary to obtain the required geological and hydrogeological information about the structure of the groundwater (GW) body, the properties of porous materials in the zone of infiltration, their deposition and the regime of GW at the site. In case of a design for smaller or less important facilities, the extent of the geological survey is usually limited; the use of GW flow models is practically excluded for the reason of a lack of financial resources.

The design for the volume of infiltrated water and an infiltration facility is carried out using variables characterizing the infiltration capacity of soil - the coefficient of infiltration (ČSN 75 9010), hydraulic conductivity (DWA, 2005) or infiltration rate (Bloomberg *et al.*, 2012). The parameters of infiltration are generally determined on the basis of the results of infiltration tests. It is also considered that such determined parameters sufficiently represent the conditions at a site, i.e. the permeability of a groundwater body, the homogeneity and anisotropy of materials, the moisture content of soil, the level of groundwater table and the depth to the impermeable basement.

Practical experience shows that the determined value of the coefficient of infiltration does not reflect the real state and relating uncertainties and may lead to the underestimation of the volume of the designed infiltration facility, particularly during a long-lasting operation of the facility. The recommended coefficient of safety $f \geq 2$ is not specified in detail.

The following text analyses the factors influencing the reliability of design for the storage volume of an infiltration facility. The effect of the individual factors was quantified by extensive numerical calculations made by the software product HYDRUS-2D (Šejna *et al.*, 2007), as well as by a professional estimate. The uncertainties of the individual parameters entering into the calculation are expressed using partial reliability factors.

MATERIALS AND METHODS

Design of the infiltration facility volume

The storage volume of an infiltration facility V_{VZ} is determined as (ČSN 75 9010):

$$V_{VZ} \geq \max_{t_c=0,t_{c,\max}} \left(V_S - V_{VSAK}\right), \tag{1}$$

where V_S is the volume of precipitation per time t_c, V_{VSAK} is the infiltrated volume per time t_c and t_{max} is the maximum duration time of constant intensity design storm (e.g. 72 hours according to ČSN 75 9010). The relation (1) may be rewritten as follows:

$$V_{VZ} \geq \max_{t_c=0,t_{c,\max}} \left(\tfrac{h_d}{1000}\cdot\left(A_{red}+A_{VZ}\right)-\tfrac{1}{f}\cdot k_v\cdot A_{VSAK}\cdot t_c\cdot 60\right), \tag{2}$$

where V_{VZ} is the storage volume of the infiltration facility (m^3), h_d is the total design precipitation (mm) with the duration t_c (min) and frequency, A_{red} is the plan view of the drained area (m^2), A_{VZ} is the area of the infiltration facility (m^2), A_{VSAK} is the infiltration area (m^2), f is the coefficient of safety recommended $f \geq 2$ by ČSN 75 9010.

In the relation (2), all variables are subject to uncertainties, however the coefficient of safety is related only to the infiltrated volume. Practical experience suggests that most designers choose the coefficient $f = 2$, namely for economical reasons. The size of the coefficient requires a more detailed discussion; it is determined on the basis of an infiltration test and is defined as follows:

$$k_v = \tfrac{Q_{ZK}}{A_{ZK}}, \tag{3}$$

where Q_{ZK} is the volume of infiltrated water during the trial infiltration test or the inflow of water into an trial object and A_{ZK} is the infiltration area in a test object, specified in the standard. For the design of an infiltration facility, the flow rate Q_{VSAK} of infiltrated water is determined according to ČSN 75 9010 from the relation:

$$Q_{VSAK} = \tfrac{1}{f}\cdot k_v \cdot A_{VSAK}. \tag{4}$$

The coefficient of infiltration k_v is determined by an infiltration test with a recommended duration of 24 hours. Other requirements for infiltration tests are specified in ČSN 75 9010. Practical experience shows that the test duration of 24 hours is seldom achieved; the common duration of infiltration tests is 6 to 8 hours.

The amount of infiltrated water Q_{ZK} changes during the infiltration test and, at the same time, the area A_{ZK} can also change. The coefficient of infiltration is thus a time-dependent variable during the infiltration test:

$$k_v(t) = \tfrac{Q_{ZK}(t)}{A_{ZK}(t)} \tag{5}$$

Nevertheless ČSN 75 9010 does not state how to evaluate the coefficient of infiltration in such a case. One of the possibilities is to derive the total infiltrated volume of water by a numerical integration of the time dependent inflow of water into an trial object during the test. Because both the coefficient of infiltration and the infiltration area change with time, Q_{ZK} is also a function of time. Using the basic relationships of GW hydraulics (Bear *et al.*, 1992), the infiltrated flow rate can be expressed by means of the equation (Lu *et al.*, 2004):

$$Q_{VSAK}(t) = \int_{A_{ZK}(t)} \mathbf{q}(x,y,z,t)\cdot dA \quad , \tag{6}$$

where $\mathbf{q}$ is the vector of the specific flow rate that is defined for the saturated and unsaturated zones as:

$$\mathbf{q} = \mathbf{K}(\theta)\cdot \text{grad } h(\theta), \tag{7}$$

where $\mathbf{K}$ is the tensor of the saturated/unsaturated hydraulic conductivity, h is the piezometric head and θ is the moisture content of soil. By substituting the equations (6) and (7) in the relation (4), it yields:

$$k_v = \tfrac{1}{A_{ZK}} \int_{A_{ZK}} \mathbf{K}(\theta)\cdot \text{grad } h(\theta)\cdot dA. \tag{8}$$

All the variables in the equation (8) are time (t) and the position (x, y, z) dependent. The hydraulic gradient depends on the shape and properties of the infiltration area, i.e. it depends on the shape of the infiltration facility, on the geological composition of the strata, on the boundary and initial conditions, i.e. on the water level in the infiltration facility, the level of the impermeable base, the initial GW level and moisture content of soil. $\mathbf{K}(\theta)$ and grad $h(\theta)$ can be determined, for example, using numerical modelling of flow in the unsaturated zone (Lu *et al.*, 2004), (Šimůnek *et al.*, 2006) and (Šejna *et al.*, 2007).

Another option that shifts the design of the volume of the infiltration facility to the safe side is to derive the coefficient of infiltration from the value achieved at the end of the infiltration test. Fig. 1 shows that the $k_v(t)$ decreases with time and is dependent on the test duration.

Design of the infiltration facility volume considering uncertainties

The performance of a geological survey and field tests is usually not extensive, mainly in case of smaller installations in which the budget is limited. In practice, numerical models are used for designing infiltration facilities less often than simplified procedures applying the coefficient of infiltration k_v. The coefficient is determined using an infiltration test that usually reflects only instantaneous local conditions. When using the coefficient of infiltration, it is considered that it expresses characteristics such as hydraulic conductivity, inhomogeneity and anisotropy of the GW body. An important factor in determining the coefficient of infiltration is the duration of an infiltration test. The coefficient of infiltration according to ČSN 75 9010 should be evaluated at the end of the test after 24 hours; in practice, however, the length of the test is usually shorter. Due to this fact, the over-evaluated coefficient of infiltration is usually obtained (Fig. 1).

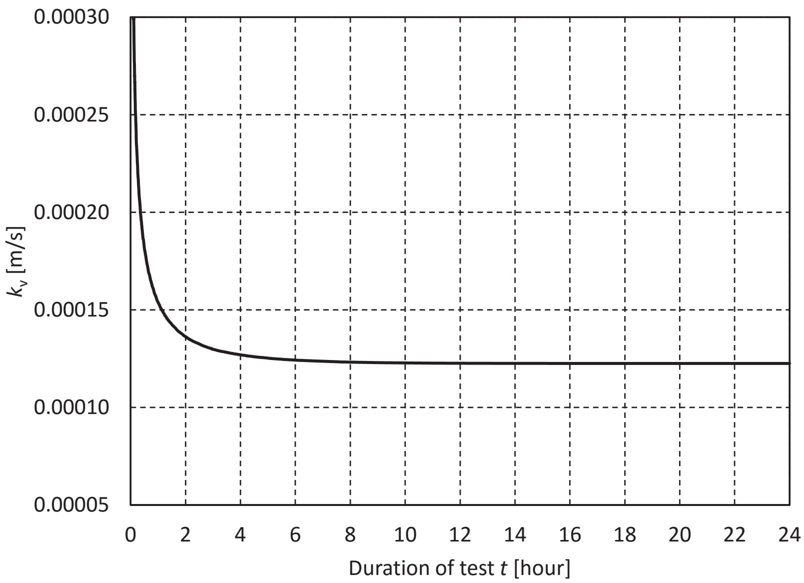
Uncertainties are brought into the solution by the changing initial moisture content of soil, the position of the GW level and the position of the impermeable basement as well. Another factor influencing the course of infiltration is the size of the infiltration facility, its spatial arrangement and type (infiltration furrow, infiltration well, perforated piping). These factors usually differ for the designed infiltration facility and for the test at which the coefficient of infiltration was determined. This study quantifies the uncertainties in the determination of the coefficient of infiltration. The objective is to express these mutually independent uncertainties. The individual uncertainties were expressed using partial reliability factor for 4 typical soils.

When undertaking a practical design the standard ČSN EN, 1990 recommends that the storage volume of the infiltration facility be determined using the condition of the limit state. This can be expressed in a more general form as follows:

$$\gamma_{VZ} \cdot V_{VZ} > \gamma_n \cdot \max_{t_c=0,t_{c,\max}} \left(\gamma_S \cdot V_S - \gamma_{VSAK} \cdot V_{VSAK} \right) \quad (9)$$

where V_{VZ} is the storage volume of the infiltration facility, V_{VSAK} is the volume of infiltrated water and V_S is the volume of precipitation water. In the condition, in a broader concept, the left side represents the "resistance" of the object and the right side "loading". The maximum of the term in parentheses on the right side of the relation (9) is determined with a whole range of the duration times t_c of the design rain. The following reliability factors are introduced into the condition (9):

- γ_{VZ} for geometric uncertainties of the volume of the flood-control storage,



1: *Example of the time pattern of the coefficient of infiltration*

- γ_n of the significance of the facility,
- γ_S expresses the reliability in the precipitation water volume,
- γ_{VSAK} expresses uncertainty in the volume of infiltrated water.

Determination of reliability factors

Storage volume of the infiltration facility

During the construction and operation of an infiltration facility the storage volume may decrease. The reasons can be inaccurate calculation, e.g. in infiltration contour furrows or ponds, imperfect construction or silting.

Larger deviations in the storage volume due to an inaccurate calculation practically do not appear in technical structures such as rectangular reservoirs, wells or boreholes. A certain error may occur in topographically more complicated areas such as infiltration belts, contour furrows or reservoirs. In case of subsurface facilities it is necessary to subtract the volume of fillings such as plastic elements or a coarse-grained soil fill. The design volume can also be decreased by imperfect construction, by using another filling material, etc. A significant reduction of the volume can result from silting. It is necessary to assess the amount of arriving sediment load, the efficiency of a cleaning device in front of the facility, and the possibility of the periodical removal of deposit from the device.

The design and choice of the size of the factor $\gamma_{VZ} \leq 1$ (the reliability guarantee of the design volume) should take account of the method of construction and the possibility of technological deficiencies such as bulging of formwork, partial filling of flood-control storage by the material of the slopes, etc. In well-designed and periodically maintained objects that were constructed with high quality, $\gamma_{VZ} = 0.95$ can be considered; the safe value is $\gamma_{VZ} = 0.90$.

The importance of the facility

It is useful to categorize the infiltration facility into three classes by its size, social and economic significance. The significance of the object is expressed using the factor of significance γ_n ; its value is determined on the basis of the analysis of social and economic significance and importance of the object, by the degree of a threat to the territory and by the amount of damage incurred in case of overloading the facility. The values of the factor can be derived on the basis of probability analysis by evaluating the losses arising from a collapse of the function of the object. A certain guide is given in Tab. I.

The volume of storm water

The volume of storm water is identified according to (Bareš *et al.*, 2013) using procedures of the sewer systems hydrology. The corresponding uncertainties are connected with determining the drained area and its reduction and determining the runoff coefficients which significantly depend on the history of precipitation and the saturation of the surface by water at the beginning of the design rainfall. Certain inaccuracy is connected with provided design precipitation totals or rainfall intensities with given duration.

The factor γ_S, expressing the reliability of the volume of rainfall water, can differ according to the drained area roughness and on its permeability. A certain role is played by the reliability of provided data on precipitation totals. For practical designs $\gamma_S = 1.20$ should be chosen for smaller areas with precipitation-gauge stations, $\gamma_S = 1.40$ for larger more rugged areas.

The volume of infiltrated water

The coefficient $\gamma_{VSAK} \leq 1$ expressing uncertainty in the volume of infiltrated water is formal in the condition (9); in practice it is necessary to express uncertainties for individual factors corresponding to the instantaneous conditions in the GW body. The following conditions are taken into account:

- the duration time of the infiltration test γ_t,
- the position of the impermeable sub-base and the GW table γ_h,
- the instantaneous degree of saturation of soil γ_{sn},
- the size and shape of the infiltration facility γ_z,
- the ageing of the facility (choking, degradation) γ_c,
- the characteristics of the GW body (anisotropy, inhomogeneity) γ_a.

The coefficient γ_{VSAK} is then expressed using partial factors listed above:

$$\gamma_{VSAK} = \gamma_t \cdot \gamma_h \cdot \gamma_a \cdot \gamma_{sn} \cdot \gamma_z \cdot \gamma_c \quad (10)$$

They can be determined using statistical evaluation of a sufficient number of field measurements, methods of analogy and numerical modelling or expert estimates.

I: *Classes of facility importance*

Class of significance	Description of facility importance	γ_n
I	Facilities with great economic and social significance; if overloaded or put out of operation, considerable damage will occur	1.05
II	Objects with medium economic and/or social significance	1.02
III	Objects a failure of which results only in negligible damage	1.00

II: *Properties of materials*

Material by USCS	θ_s	θ_r	α (1/m)	n	k_s (m/s)
Fine Sand (SW)	0.430	0.045	14.5	2.68	$1.0 \cdot 10^{-4}$
Sand with Fines (SP)	0.410	0.057	12.4	2.28	$5.0 \cdot 10^{-5}$
Silty Sand (SM)	0.410	0.065	7.5	1.89	$1.0 \cdot 10^{-5}$
Clayey Sand (SC)	0.430	0.078	3.6	1.56	$1.0 \cdot 10^{-6}$

In this study, the reliability factors in the relation (10) were determined by numerical simulations in the software HYDRUS-2D (Šimůnek *et al.*, 2006), (Šejna *et al.*, 2007), which enables the solution of the flow in the saturated and unsaturated zones, assuming a two-dimensional approximation of flow. The theoretical background and detailed description of the software are beyond the scope of this text, the reader is referred to the literature sources given above.

Numerical simulations were made for 4 typical materials classified by United Soil Classification system (USCS) (ASTM, 2011) with properties according to Tab. II for the infiltration facility according to ČSN 75 9010, Annex. G.

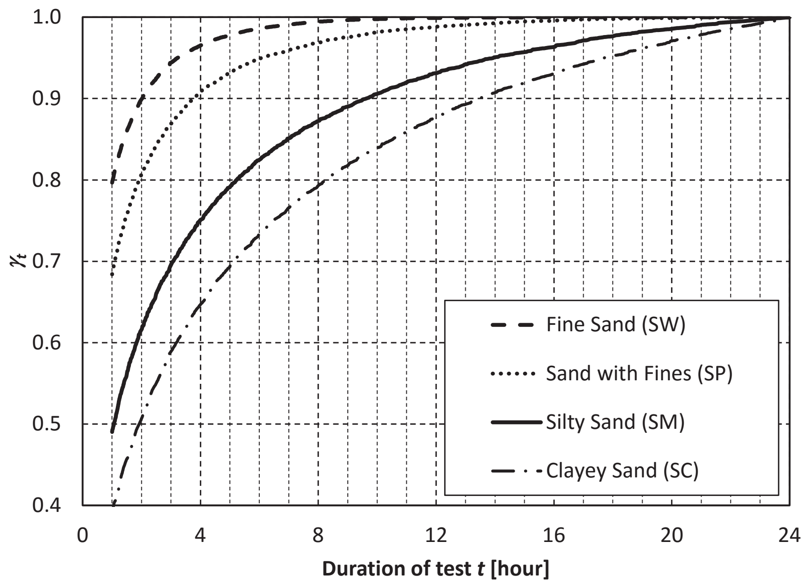
In Tab. II, θ_S means the moisture content of saturated soil, θ_r is the residual moisture content, α is the reciprocal of the input value of air, n is the shape coefficient of the water retention curve (Van Genuchten, 1980), and k_s is the saturated hydraulic conductivity. The following paragraphs describe the derivation of the partial reliability factors in (10) with the fulfilment of independence of the conditions in their determination.

The duration time of the infiltration test

The recommended length of the infiltration test according to ČSN 75 9010 is 24 hours. Numerical tests show that after this period the evaluated coefficient of infiltration does not change anymore (Fig. 1). For this reason the 24-hour length of duration of the infiltration test is considered to be referential. The factor γ_t expressing the effect of the length of duration of the test is defined as follows:

$$\gamma_t(t) = \frac{k_v(t)}{k_{v24}}; t < 24 \text{ hours} \quad (11)$$

where $\gamma_t(t)$ is the partial reliability factor relative to the length of duration of the infiltration test, k_{v24} is the coefficient of infiltration determined after 24 hours of the test and $k_v(t)$ is the coefficient of infiltration determined at the time t. The factor $\gamma_t(t)$ was determined under the conditions of infinite depth to the impermeable basement without the effect of the GW table. The relationship $\gamma_t(t)$ according to (11) for typical soils is depicted in Figs. 2, 3, 4 and 5. The graphs show that for less permeable materials the coefficient of infiltration obtained from a shorter infiltration test should be reduced; e.g. for sandy materials it is sufficient that the test duration is about 8 hours when infiltration becomes steady.



2: *Dependence of $\gamma_t(t)$ on duration of infiltration test*

Effect of impermeable sub-base and groundwater table depth

Different depths of the GW table and of the impermeable base beneath the infiltration facility influence the volume of infiltrated water and the coefficient of infiltration. For different combinations of depth to the impermeable basement and depth to the GW table, the factor γ_{h_i} was determined from the relation:

$$\gamma_{h\_i} = \frac{k_{v24\_h}(h_{GW}, h_{IS})}{k_{v24}} \tag{12}$$

where $k_{v24\_h}(h_{GW},h_{IS})$ is the coefficient of infiltration after 24 hours for the corresponding depth h_{GW} to the GW table and the depth h_{IS} to the impermeable basement beneath the infiltration facility. k_{v24} is the coefficient of infiltration after 24 hours influenced neither by the position of the GW table nor by the level of the impermeable basement. The relationships of the partial reliability factor γ_{h_i} for sand according to the equation (12) are depicted in Figs. 3, 4, 5, 6.

For determining the factor γ_h it is necessary to determine the factor γ_{h_i} for the conditions of the infiltration test (γ_{h_ZK}) and the conditions of the infiltration facility (γ_{h_VSAK}). The resulting factor γ_h is calculated from the relation:

$$\gamma_h = \frac{\gamma_{h\_VSAK}}{\gamma_{h\_ZK}} \tag{13}$$

The effect of the degree of saturation (moisture content) of soil

The instantaneous initial degree of saturation of soil plays a certain role in carrying out an infiltration test and also in the infiltration of rainwater in the already-constructed infiltration facility. Uncertainty in the initial degree of soil saturation is reflected by the reliability factor γ_{sn} expressed for typical soils for the infiltration test duration of 24 hours. It is expressed by the following ratio:

$$\gamma_{sn} = \frac{k_{v24}(S_w)}{k_{v24}(S_{WR})} \tag{14}$$

where $k_{v24}(S_w)$ is the coefficient of infiltration for the given initial degree of saturation S_W, $k_{v24}(S_{WR}) = k_{v24}$ is the coefficient of infiltration for the material with the initial degree of saturation S_{WR} corresponding to the residual moisture content q_R. The relationship between the factor γ_{sn} for typical materials and the degree of saturation is shown in Fig. 7.

The effect of the shape and size of the infiltration facility

The infiltration test should be carried out on an trial pit or borehole (ČSN 75 9010). Deviations in the shape and dimensions of the designed infiltration facility and equipment in the infiltration test can cause a difference in the velocity and volume of infiltrated water. With the aim to quantify the effects above, a number of scenarios of configuration with different geometric parameters of the infiltration facility were numerically calculated. Based on (Dušek *et al.*, 2009) with taking into account calculated result the value of reliability factor γ_z based on used test device can be considered:

- trial pit by ČSN 75 9010
  $\gamma_z = 0.95$;
- double ring infiltrometer by ČSN EN ISO 22282-5
  $\gamma_z = 0.50$;
- single ring infiltrometer by ČSN EN ISO 22282-5
  $\gamma_z = 0.40$;
- borehole by ČSN EN ISO 22282-2
  $\gamma_z = 0.50$.

The effect of ageing of the facility

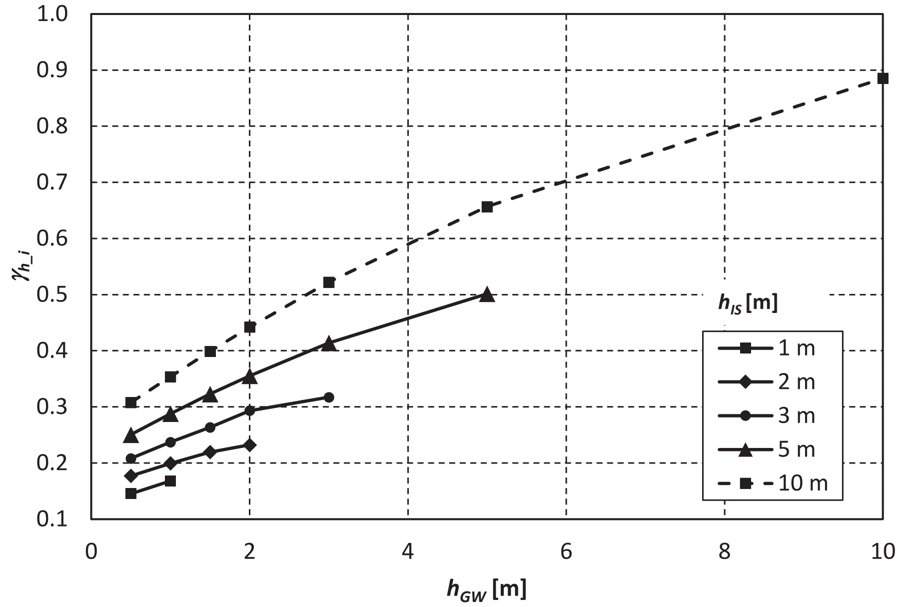
The ageing of the infiltration facility is governed by clogging of surrounding soil. Its course was studied e.g. by Kovács (1981). His measurements show that clogging takes place especially in the layer about 0.50 m thick beneath the surface of infiltration; permeability decreases with time towards the surface of the infiltration facility, in which hydraulic conductivity can drop by up to several orders of magnitude after about 7 days. The factor γ_c should be chosen with regard to the efficiency of water pre-treatment in front of the entrance to the infiltration facility and/or to the possibilities of its regeneration. It is recommended that γ_c be chosen at least at 0.8; in case of impossible regeneration and unreliable pre-treatment, even at $\gamma_c = 0.1$.

The effect of anisotropy and inhomogeneity

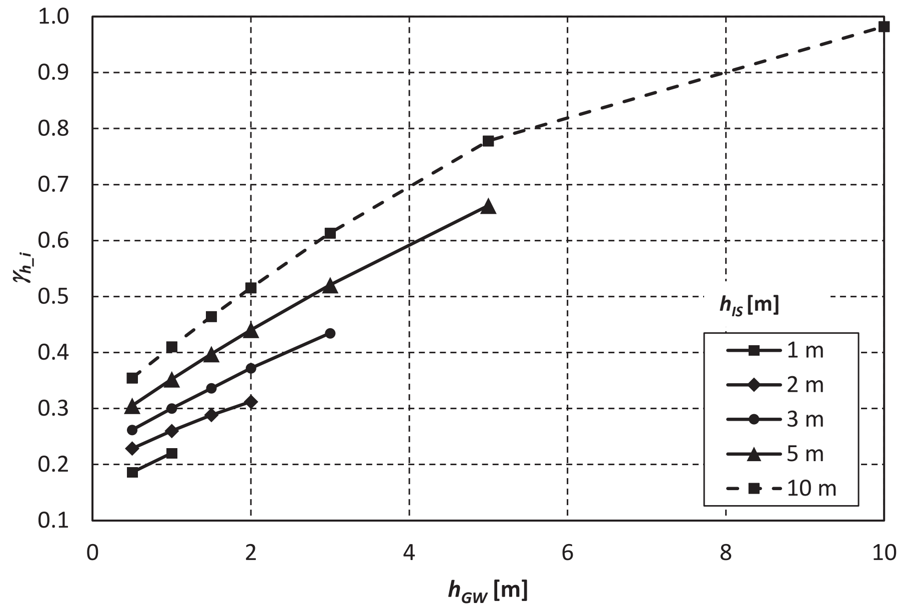
When conducting the infiltration test, it is assumed that the determined coefficient of infiltration already implies the effect of anisotropy of the permeable filtration environment. In the event that inhomogeneity could be expected in the form of alternation of more permeable layers with less permeable ones beneath the infiltration facility, a relationship was derived between the factor g_a and the ratio of the hydraulic conductivity of the less permeable layer located 0.5, 1, 2 and 3 m below the level of infiltration (beneath the bottom of the infiltration facility) to the material in which the infiltration was conducted (Figs. 8, 9 10, 11). In case of a difference in the hydraulic conductivity of approximately horizontal layers (larger than five-fold), it is necessary to consider the layers as relatively impermeable and to use the procedure applying Eq. (12) and (13).

RESULTS FROM TWO DESIGN APPROACHES

For demonstrating the above-given approaches – according to ČSN 75 9010 by Eq. (2) with $f = 2$ and using the method of limit states



3: *Dependence of γ_{h_i}, on depth of impermeable sub-base and groundwater table - Fine Sand (SW)*

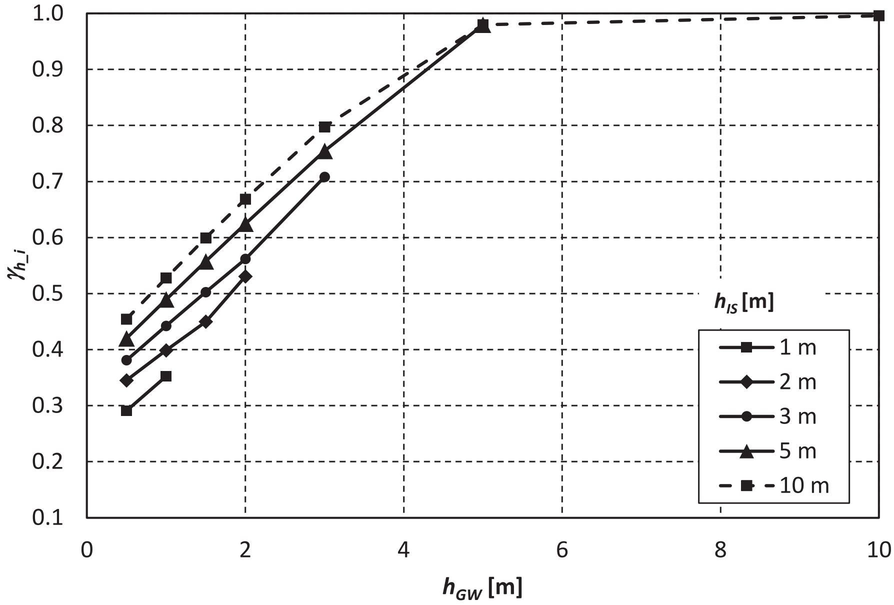


4: *Dependence of γ_{h_i}, on depth of impermeable sub-base and groundwater table - Sand with Fines (SP)*

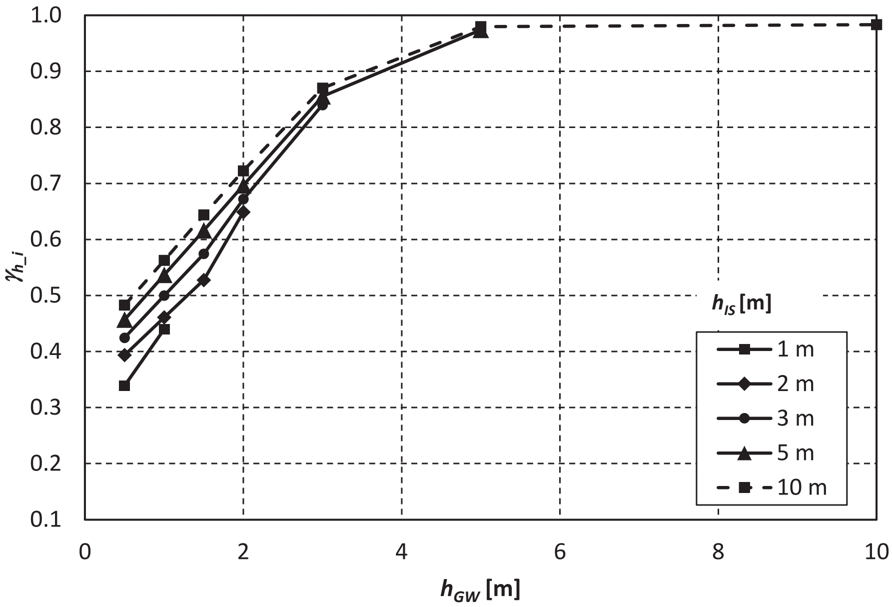
by Eq. (9), the calculation of the storage volume of a surface infiltration facility is presented. A drained area is located on the Prague territory and the reduced area is $A_{red} = 527$ m^2. The coefficient of infiltration is $k_v = 1.10^{-5}$ m/s and was estimated with double ring infiltrometer. The coefficient of safety of infiltration is considered as $f = 2$ and the rainfall periodicity $p = 0.2$ year^{-1}. In case of the procedure according to limit states, different conditions were chosen in conducting an infiltration test and in the operation of the infiltration facility.

In the infiltration test, the depth $h_{GW} = 4.0$ m of GW table beneath the bottom of a trial pit, the depth $h_{IS} = 5.0$ m of the impermeable basement beneath the pit bottom, the infiltration test lasted $t = 8$ hrs. The initial degree of saturation is $S_w = 0.3$, which approximately corresponds to the moisture content 0.123.

In the infiltration facility, the GW table is considered to be $h_{GW} = 4.0$ m beneath the bottom of the facility, the position of the impermeable basement $h_{IS} = 5.0$ m beneath the facility. The initial soil saturation can reach up to $S_w = 0.7$. At a depth of



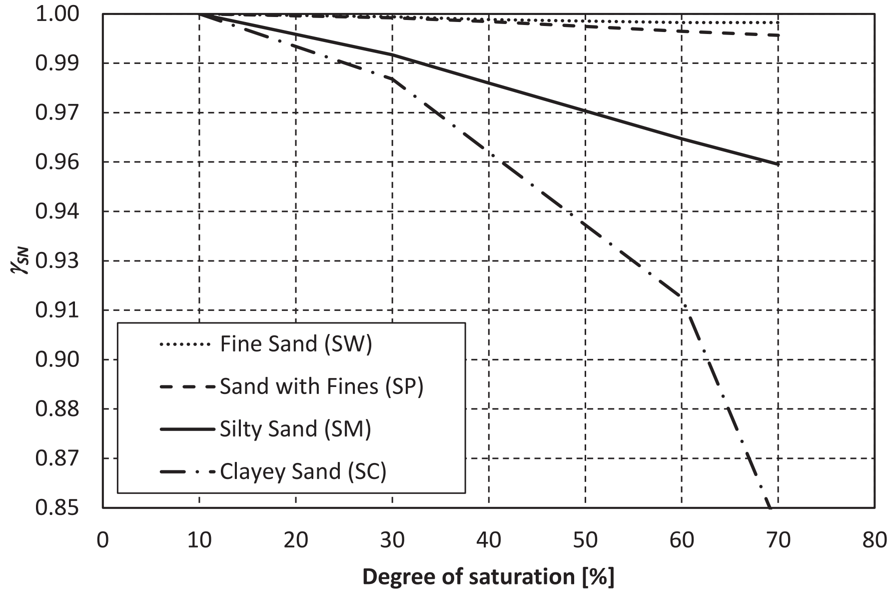
5: *Dependence of γ_{h_i}, on depth of impermeable sub-base and groundwater table - Silty Sand (SM)*



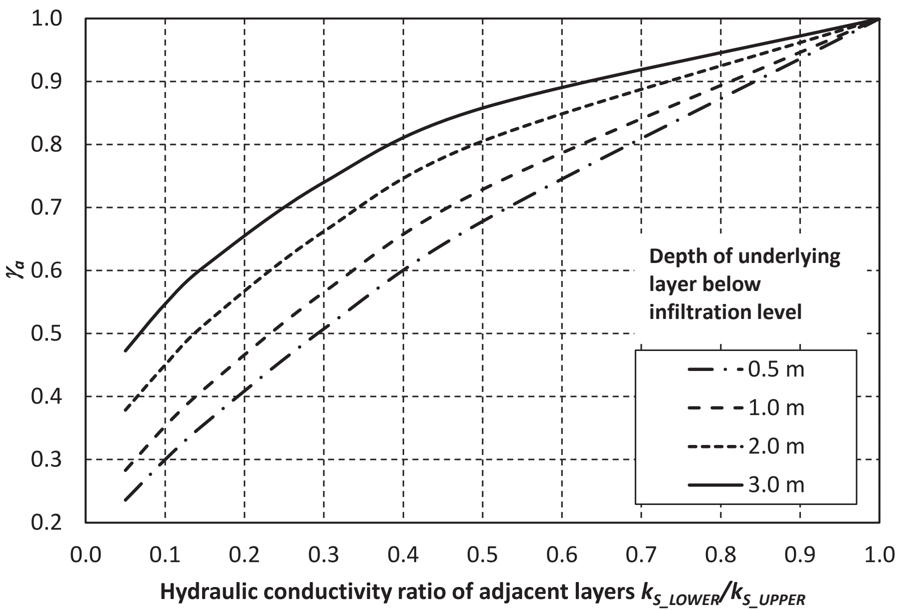
6: *Dependence of γ_{h_i}, on depth of impermeable sub-base and groundwater table - Clayey Sand (SC)*

3.0 m beneath the bottom of the facility, a layer was encountered with half the hydraulic conductivity than when drilling the trial pit. For the given conditions, the following values of the reliability factors were determined using the above-depicted graphs supplemented with expert estimates:

- for geometric uncertainties in the flood-control storage
  $\gamma_{VZ} = 0.95$,
- for the significance of the facility
  $\gamma_n = 1.02$,
- for the reliability of the volume of precipitation water
  $\gamma_S = 1.20$,
- for the duration time of the infiltration test
  $\gamma_t = 0.87$,
- for the position of the impermeable base and GW table
  $\gamma_h = 1.00$,
- for the instantaneous degree of saturation of soil
  $\gamma_{sn} = 0.95$,



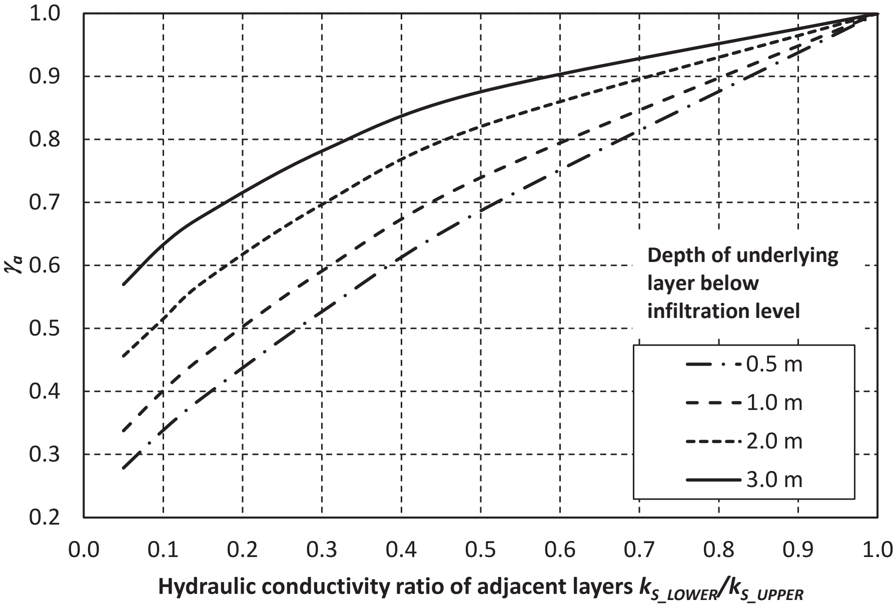
7: *Dependence of γ_{sn} on degree of saturation*



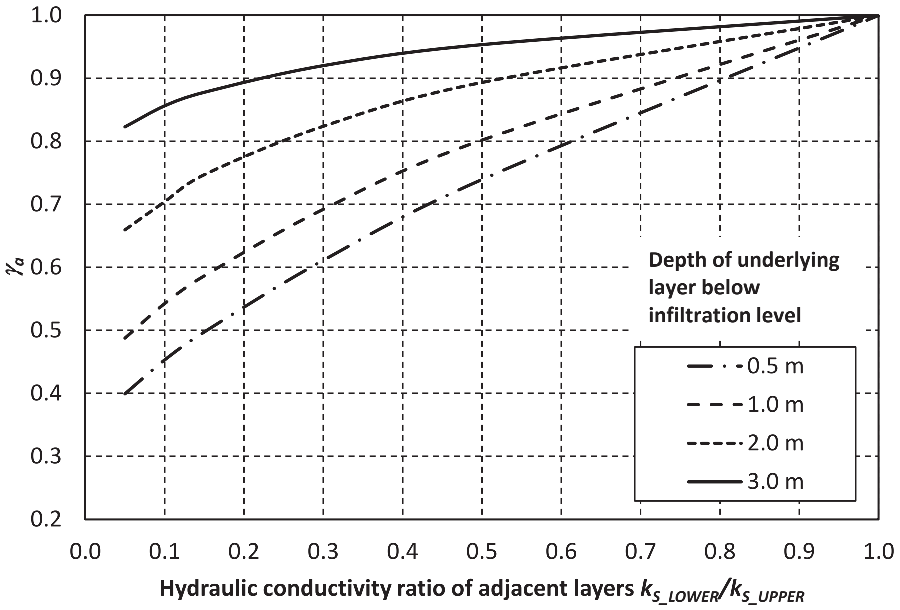
8: *Dependence of γ_a on conditions of hydraulic conductivities of underlying layers - Fine Sand (SW)*

- for the size and shape of the infiltration facility
  $\gamma_z = 0.50$,
- for the ageing of the facility (choking, degradation)
  $\gamma_c = 0.50$,
- for the characteristics of the GW body
  $\gamma_a = 0.80$.

The calculation of the storage volume V_{VZ} of the facility was determined for design precipitation totals with the duration from 5 minutes to 72 hours according to the Eq. (2) in ČSN 75 9010 and according to the condition (9) incorporating partial uncertainties. The relationship expressing the required storage volume as a function of the rainfall duration is shown in Fig. 12. The maximum volume of the facility according to ČSN 75 9010 is, 19.0 m^3 and using the procedure proposed is 29.1 m^3. It is obvious that the storage volume of the infiltration facility determined according to ČSN comes out under-dimensioned by roughly 10 m^3.



9: *Dependence of γ_a on conditions of hydraulic conductivities of underlying layers - Sand with Fines (SP)*

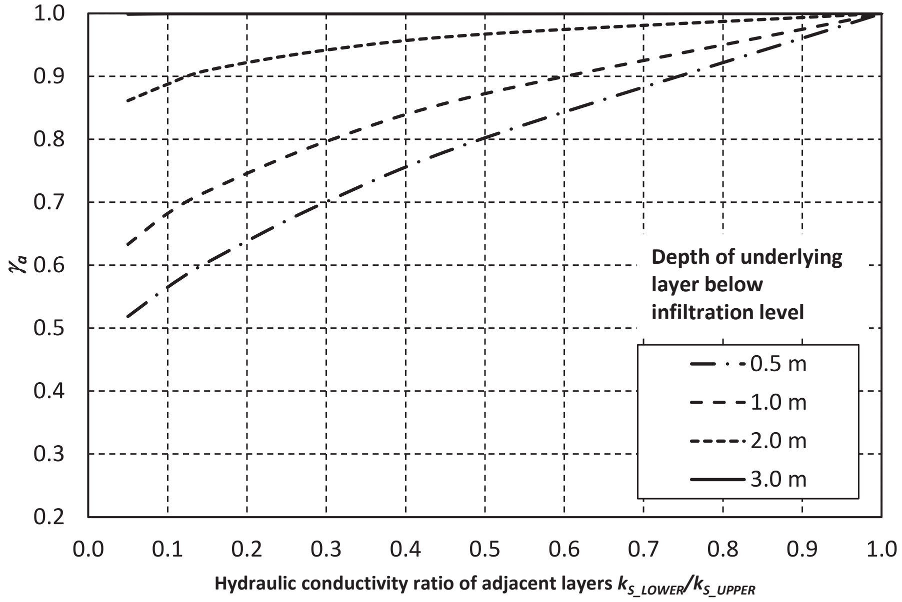


10: *Dependence of γ_a on conditions of hydraulic conductivities of underlying layers - Silty Sand (SM)*

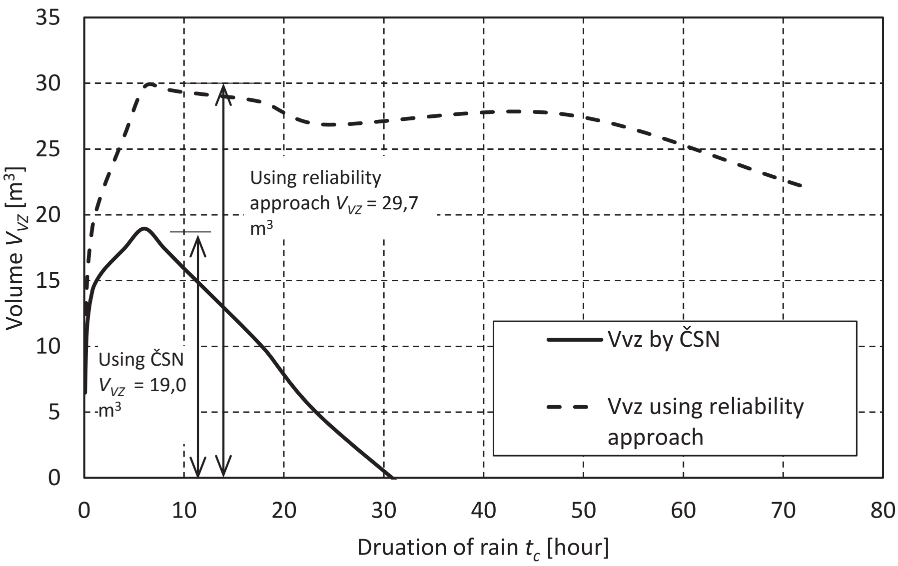
DISCUSSION AND CONCLUSION

A procedure is recommended in ČSN 75 9010 for determining the storage volume of an infiltration facility, in which the coefficient of infiltration k_v is introduced. According to the standard it "characterizes the infiltration capability of the soil in a studied site". In practical calculations ČSN 75 9010 recommends to reduce determined coefficient of infiltration by the coefficient of safety $f \geq 2$. The analysis carried out in more detail shows that numerous input variables are involved in the design, loaded by uncertainties arising from not meeting design parameters of the infiltration facility, from the reliability of hydrological data and particularly from the limited extent and reliability of the survey.

This paper defines the individual variables involved in the calculation, and analyses the factors that influence the design of the storage volume of the infiltration facility. The effect of each factor was quantified using extensive numerical calculations made by the software HYDRUS-2D, (Šimůnek *et al.*,



11: *Dependence of γ_a on conditions of hydraulic conductivities of underlying layers - Clayey Sand (SC)*



12: *Comparison of two design approaches*

2006), (Šejna *et al.*, 2007). Uncertainties in the determination of the storage volume are expressed by partial reliability factors quantified for 4 typical soils.

The proposed procedure taking account of uncertainties in each parameter is demonstrated on an example of comparison. The results of the calculation show that the procedure according to ČSN 75 9010 can ultimately lead to the significant under-dimensioning of the storage area, particularly by over-evaluating the infiltration capability of the infiltration facility.

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