POLLACK PERIODICA
An International Journal for Engineering and Information Sciences
DOI: 10.1556/606.2019.14.2.18
Vol. 14, No. 2, pp. 201–210 (2019)
www.akademiai.com

IMPLEMENTATION OF THE PERCOLATION FACILITIES FOR RAINWATER RUNOFF REDUCTION

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Received 11 December 2018; accepted 22 January 2019

Abstract: The article is aimed at finding out the behavior of the combined sewer network in the event of the occurrence of extreme precipitation events, which are associated with changes in the rainfall - runoff process in the urbanized area. Given the current situation of increased surface runoff in the urbanized area, it is necessary to extend the use of objects to reduce rainfall to the sewerage network. Part of the case-study was the design of percolation facilities in town Vráble, which are among the most used and most effective reduction measures. After designing the infiltration equipment and reducing the amount of rainwater discharged into the single sewerage network, the assessment of the sewerage network is satisfactory throughout the whole territory.

Keywords: Rainfall-runoff process, Case-study, Sewerage network

1. Introduction

As a result of the increase in the number of impermeable surfaces in the urbanized area, it is the acceleration of the surface runoff, which causes several negative impacts on the environment. The consequences of climate change only aggravate these phenomena and cause sudden changes in weather, short heavy rain with varying intensities and long periods of drought [1]. The lack of permeable surfaces causes the raising of surface runoff to the sewer system. Accelerating the drainage process leads to concentration speeds expanding, peak flow rates and the possibility of local floods [2]. The solution of sewerage networks congestion is therefore the retention and efficient

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management of rainwater at the site of their impact. The tendency is to increase green areas in cities and to improve water cycle conditions in urbanized areas [3]. The water retention problem in the country is dealt with in the Water Plan of Slovakia in accordance with the Water Framework Directive and unreservedly supports measures for the construction of water retention facilities in urbanized areas [4]. The rainwater runoff in the sewer network is controlled by means of the combines sewer overflows, rainwater separators. These facilities represent a major pollutant of receiving water. Attempts are currently being made to reduce the number of overflows during extreme precipitation. Therefore, alternative solutions for surface runoff are being sought. A preferred method of reducing the surface runoff is percolation of rainwater. The Action Plan (AP) issued by the Ministry of the Environment contains alternatives to solving the problem of drought and water scarcity. The AP describes in preventive measures, settlement landscape details of activities. It explains the four measures that will be supported under the program [5].

The use and retention of rainwater in Slovakia is not yet one of the leading measures for regulating the amount of wastewater.

Several boundary conditions are considered when assessing sewer networks. These boundary conditions include the size of the surface runoff, which greatly contributes to the reduction of the capacity of the sewer network. Surface runoff size is determined based on model rainfall. The hydraulic model of flow in the sewer network plays an important role in assessing sewer networks. Modeling is based on information about the sewer network and model rainfall [6].

The aim of this study is to propose alternative solutions for draining rainwater from urbanized areas in the town of Vráble. Earlier analyzes based on modeling of the sewer network status at different precipitation intensities have detected overloaded sections of the network. In the overloaded sections, it is necessary to take measures to reduce the rainfall inflow into the sewerage network. The aim of the paper is to design the percolation facilities at the Gymnasium and Primary School in Vráble.

2. Methodology

2.1. Case-study area

The interested territory lies in the north-eastern part of the Danube Plain in the alluvial plain of the Žitava River, which separates the Žitavská and Pohronská hills. From the point of view of geological division, the territory is included in the tertiary to quaternary basin, Pannonian basin. The area is built with younger third-grade sediments. There is also clay, gravel, gravel-sand, which extend up to the surface on the slopes. Locations contain sand layers at a depth of 100-200 cm [7].

The permeability of the soil environment in the area of interest changes due to irregular river sedimentation and therefore the filtration coefficient ranges from $5.3 \cdot 10^{-4}$ - $1.3 \cdot 10^{-3}$ [$m.s^{-1}$]. The groundwater level is located at 4.50 - 6.0 m depths below the terrain [8].

Rainfall data are obtained in Slovakia from 68 rain gauge stations, which are evenly distributed throughout the country. In Vráble, rain gauge station is not located.

Therefore, local parameters are interpolated based on the three closest stations (Nitra, Nový Tekov, Svätuša).

2.2. Model rains

Rain is one of the most important input parameters in the hydrology of urbanized areas. They share a high degree of flow in combined sewer networks, especially in urbanized areas. The short term rainfall is important for sizing sewer profiles. The rain differs with the different duration, rainfall and average intensity.

Design rainfall is used to design new sewers, sewage facilities or to expand existing sewer network. The design rainfall is characterized by periodicity, duration, time and space division of rain and average intensity or rainfall [6].

Block rainfall are defined by the duration, the periodicity of the occurrence, the constant specific rainfall yields or intensity. It presents the simplest but also least likely course of precipitation. Block rainfall has a constant intensity throughout its duration and therefore has a rectangular shape. The disadvantage of using block rain is their regular shape, which fails to simulate the course of real rain. The block rains with periodicity p=0.2 and p=0.5 were used for the case-study.

Synthetic model rain with time variable intensity variability simulates the variable course of intensities in the time course of real rain. Synthetic rain then represents artificially created hyetographs in order to achieve more accurate design solutions compared to block rainfall intensities with constant intensities. This is especially important when using more exact computational methods that describe in detail surface rain runoff and simulate non-stationary flow in the sewer network [6], [9]. There are few types of synthetic model rains e.g. model rain created by Keifer and Chu, model rain type Yen and Chow or Šifald model rain [6]. The intensity profile of rain episodes depends mainly on the rainfall type. They differ in the distribution of the rainfall uniformity in time and position of maximum rainfall [6], [9].

Historical rain represents rain episodes that have occurred in the past. Their course expresses hyetographs measured by intensity gauge. Historical rainfall is not characterized by repetition or periodicity and does not have the character of idealized rains [6], [9].

2.3. Evaluation of sewer networks - Assessment of sewer network

The hydraulic calculation of the sewer network was evaluated and published in the previous project [9]. After the hydraulic simulation of the sewer network loaded to blocked rain, 18.65% of the network nodes were found to be overloaded [9]. Hydraulic modeling can be used not only for modeling the flow in the sewerage network, but also for modeling the flow in Waste Water Treatment Plants (WWTP) e.g. according to Hrudka et al. [10]. The next step will be to find a suitable alternative way of solving rainwater drainage from the urbanized territory.

2.4. Parameters of the model rain

The calculation models were made for the periodicities of p=0.5 and p=0.2. The calculation of specific yields in locations that do not have their own observations can be made from the local parameter values of the three closest rain gauge stations. The condition is that these meteorological stations must come from a flat or common valley or have similar orographic characteristics. *Table I* and *Table II* represent input data (local parameters) for model rainfall calculations.

Table I

Local parameters (K, B, a) for Vráble with periodicity p=0.2

periodicity p=0.2						
Input parameters	Station	Nitra	Nový Tekov	Svätuša	Interpolation results	Vráble
	K	3109.5	3446.5	3610.8		K = 3399.9
	B	4.36	5.07	5.02		B = 4.83
	a	0.913	0.912	0.908		a = 0.911
	L	17.4	16	15.3		
	m	0.185				

where *K, B, a* are the parameters of block rain curve [-], *L* is distance between rain gauge stations [m], *m* is interpolation parameter [-].

Table II

Local parameters (K, B, a) for Vráble with periodicity p=0.5

periodicity p=0.5						
Input parameters	Station	Nitra	Nový Tekov	Svätuša	Interpolation results	Vráble
	K	2552.7	2745.5	2881.4		K = 2733.6
	B	4.35	4.71	4.42		B = 4.50
	a	0.915	0.921	0.919		a = 0.92
	L	17.4	16	15.3		
	m	0.185				

Fig. 1 present the pattern of block rainfall model at periodicity p=0.2 and p=0.5.

Keifer and Chu synthetic model rain were used for to illustrate the difference in rainfall when using another model. In this model rain, the only statistical parameter is the time position of the maximum intensity. The rain amount and its peak intensity are derived from the block rains curve [11]. The course of synthetic model rain can be found in *Fig. 2*.

2.5. Percolation of precipitation water

Recent research on sustainable urban development in the retention of rainwater in urban areas highlights the need for policy changes in the drainage of rainwater. It is an attempt to reduce the rainfall flow in the sewerage network by means of nature close to measures that might also be able to reduce the adverse effects of urbanization in cities

[12]. The rainfall is reduced and held in the landscape by facilities for the percolation of precipitation runoffs. It can be distinguished according to the following criteria:

- Centralised or decentralised;
- Storage capability;
- Hydraulic charging;
- Surface requirement [13].

The basis of technical solutions for facilities is:

- Surface percolation;
- Swale percolation;
- Swale - infiltration trench element;
- Infiltration trench and pipe - infiltration trench percolation;
- Shaft infiltration;
- Basin percolation;
- Swale - infiltration trench system [6].

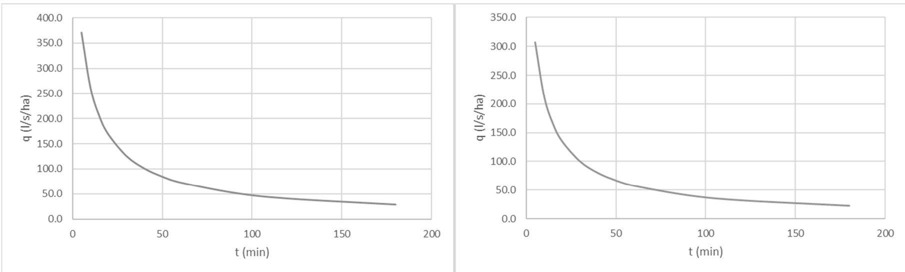

Fig. 1. Block rain curve for city of Vráble at periodicity p=0.2 and p=0.5

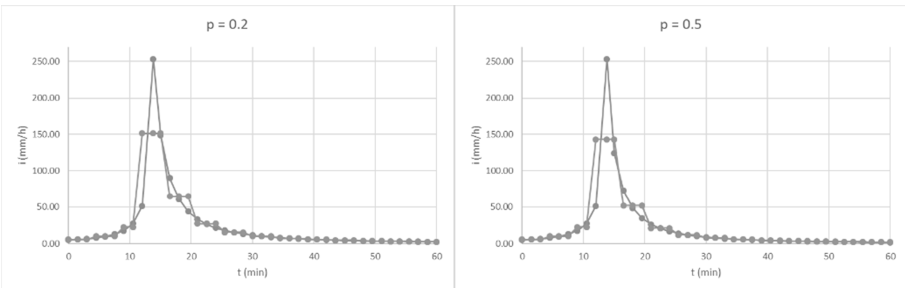

Fig. 2. Synthetic model rain curve for city of Vráble at periodicity p=0.2 and p=0.5

Rainwater percolation is among the ecologically beneficial ways of managing rainwater, which has the advantage of eliminating the water inflow from the roof to the sewer network. As a result of the construction of efficient infiltration facilities, the fewer burdens on the receiving water are the number of possible overflows. The design of infiltration and percolation devices is in accordance with German standard: Planning, construction and operation of facilities for the percolation of precipitation water (DWA-A 138) [13] because the Slovak standard does not exist.

2.6. Design of infiltration devices

According to the German standard [13], the infiltration shaft is defined as a sub-surface leakage device for drainage of rainwater from the surface runoff, where the incoming water is accumulated and then diverted to the surrounding environment. There are two design types of shaft:

- Type A with infiltration at the bottom of the shaft through the filter layer and along the side walls of perforated concrete rings;
- Type B whose structure differs by placing perforated rings exclusively under the filter layer [13].

The percolation flow is determined based on the parameters of the shaft compartments and the groundwater level. It is preferable to design the infiltration shafts only in areas with sufficient depth of groundwater. During the hydrogeological survey of the site with a higher morphological position, the underground water was not found in the studied depth [13].

The infiltration shaft is dimensioned based on the impoundage height determination. Dimensional equation is derived from the equations to determine the effective percolation area, the required volume of the shaft and the storage volume of the shaft

$$z = \frac{A_n . 10^{-7} . q_{0.2} - 0.3927 \cdot d_v^2 \cdot k_f}{0.01309 d^2 \cdot f_z^{-1} \cdot t^{-1} + 0.7854 d_v \cdot k_f} = \frac{a \cdot q_{0.2} - b}{m \cdot t^{-1} + n}, \tag{1}$$

where z is the impoundage height [m]; $q_{0.2}$ is the relevant rainfall intensity p=0.2 [l. s^{-1}. ha^{-1}]; d is the internal diameter of the shaft [m], d_v is the external diameter of the shaft [m]; f_z is the surcharge factor in accordance with German Standard Dimensioning of Storm-water Holding Facilities [14]; t is the duration of the dimensioning rainfall [min]; k_f is the permeability coefficient of the saturated zone [m.s-^{1}]; A_n is the connected impermeable surface [m^2]; a, b, m, n are parameters of dimensioning equation.

Another type of sub-surface percolation device is the infiltration trench. The advantage of the infiltration trench relative to the shaft is the size of the exfiltration surface. There are two types of trenches:

- Infiltration trench filled with gravel;
- Pipe - infiltration trench element filled with gravel [13].

The length (L) of the infiltration trench is dimensioned by determining the block rain intensity. Eq. (2) determines the procedure for calculating the length of the infiltration trench and Eq. (3) specifies the value of the accumulation coefficient,

$$L = \frac{6 \cdot 10^{-6} \cdot K_p \cdot S_r \cdot t \cdot q_{(t,p)}}{b \cdot h \cdot s + 30 \cdot k_f \cdot t(b + 0.5h)}, [\text{m}], \tag{2}$$

$$s = \left[0.25\pi \cdot d^2 + s_s\left(b \cdot h - 0.25\pi \cdot D^2\right)\right](b \cdot h)^{-1}, [\text{-}], \tag{3}$$

where Kp, is the parameter of block rain curve [-]; h is the height of the infiltration trench [m]; b is the width of the infiltration trench [m]; s is the storage coefficient of the filler material of the infiltration trench (gravel filling); s_s is the overall storage coefficient for the pipe trench (0.35); S_r is the connected impermeable surface [m^2]; k_f is the permeability coefficient of the saturated zone [m.s^{-1}]; D is the external diameter of the pipe [mm]; d is the internal diameter of the [mm]; q is the relevant rainfall intensity p 0.2 [l. s^{-1}. ha^{-1}]; t is the duration of the dimensioning rainfall [min].

3. Results

3.1. Alternative No. 1 - Suggestion of percolation shafts

The depth of the intake shaft is proposed after determining the impoundage height. The impoundage height also depends on the parameters of the concrete rings that determine the diameter of the shafts. Several parameters must be considered when designing the depth and dimensions of the infiltration shafts: non-freezing depth of the inlet pipe, thickness of the filtration layer, thickness of sandy fine gravel layer and impoundage height. The internal diameter of the percolation shaft was designed according to the available sizes of precast concrete d=2200 mm, outer diameter D=2500 mm. The freezing depth at the site of Vráble is at a depth of 1 m below the surface. The filter layer in designing the A-shaft has a thickness of 0.5 m. *Table III* presents the results of the design.

Table III

Height of percolation shafts

	Connected impermeable surface [m^2]	Number of shafts	Impoundage height [m]	Depth of the shafts [m]
Building no. 1 – Primary School	483	2	1.12	3
Building no. 2 – Primary School	1579	6	1.25	3
Building no. 1 – Gymnázium	954	4	1.11	3
Building no.2 - Gymnázium	1210	6	0.9	2.5

3.2. Alternative No.2 - Infiltration trenches design

Three infiltration trenches with 8/32 mm gravel filling were designed for the grammar school (Gymnázium) and the primary school. They separately drain the roof of grammar school and elementary school. The grammar school building consists of two buildings whose floor area is 2164 m^2. Therefore, from the design point of view, it is preferable to design two infiltration trenches for grammar schools. The connected impermeable surface of building A is 954 m^2 and building B is 1210 m^2. The connected impermeable surface of the primary school building is 2062 m^2.

The local parameters of the block rain curve of the given area for the p=0.2 and p=0.5 periodicity, the ground areas of the drained areas, permeability coefficient of the saturated zone, storage coefficient of the filler material, the width and the depth of the trench were used as input data for the calculation of the infiltration trenches. The width of the trench was determined based on the terrain configuration and the spatial layout of the site (b=1 m). The depth of the trench was chosen according to the DWA A-138E [13] Standard that the groundwater level is min. 1.0 m below the bottom of the filtration zone of the percolation device (h=2.5 m). *Table IV* and *Table V* presents the results of the calculation of the length of the infiltration trenches (for p=0.2 and p=0.5).

Table IV

Length of infiltration trench for elementary schools according to Standard [13]

	p = 0.2	p = 0.5
t_{max} [min]	9.73	9.95
L [m]	33.37	27.75

Table V

Length of infiltration trench for elementary schools according to Standard [13]

	Trench A		Trench B	
	p= 0.2	p = 0.5	p= 0.2	p = 0.5
t_{max} [min]	9.73	9.95	9.73	9.95
L [m]	15.44	12.84	19.58	16.28

4. Discussion

Based on the data from *Table IV* and *Table V*, the infiltration trenches lengths were proposed as follows: For a primary school, one trench with depth of 2.5 m, width 1 m and length 33.5 m were proposed. For grammar school buildings, two separate infiltration trenches have been designed with the same width and depth parameters as in the previous case. The length of the infiltration trench that draws rainwater from the roof of the main building of grammar school is 20 m and the proposed length of the trench for draining water from the roof of the second building is 15.5 m.

For grammar school - Gymnázium of Vráble and for Viliam Záborský Primary School were designed eighteen percolation shafts. Twelve shafts have the same parameters with a depth of 3 m. Six percolation shafts with a depth of 2.5 m were designed for building No. 2 of the grammar school. Subsequently, the assessment of the depths of the shafts with respect to the depth of the groundwater level was carried out and all the proposed percolation facilities complied with this condition. *Fig. 3* shows the location of infiltration trenches and percolation shafts.

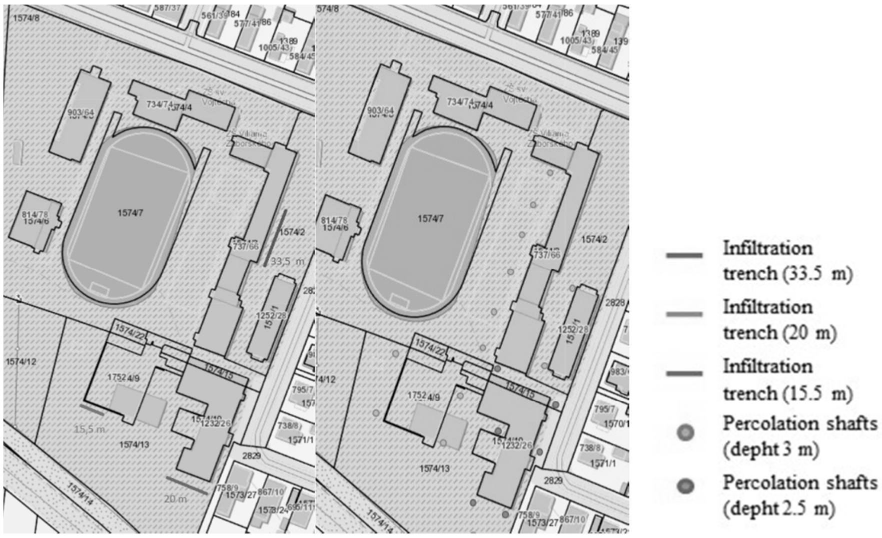

Fig. 3. Location of infiltration trenches and percolation shafts

5. Conclusion

The aim of the paper was to approach the issue of efficient rainwater management in urbanized areas. The gradual increase of impermeable surfaces in cities has the problem of an accelerated surface runoff. Consequently, the combined sewer network is not able to carry out his function. For this reason, percolation facilities are increasingly used to reduce the amount of rainwater that is discharged through the sewerage network.

Percolation of precipitation water is one of the most widespread and environmentally friendly ways to treat rainwater. The greatest benefit is the reduction of the surface runoff and thus the reduction of the total volume of rainwater in the sewer network.

Acknowledgements

This article was created with the support of 'Mladý výskumník STU' grant under the AZOPPEDU acronym, funded by the 'Rectors office of the STU in Bratislava. This article was created with the support of the Ministry of Education, Science, Research and Sport of the Slovak Republic within the Research and Development Operational

Programme for the project ‘University Science Park of STU Bratislava’, ITMS 26240220084, co-funded by the European Regional Development Fund.

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