Measurements of infiltration efficiency of percolation facilities for its safety operation in real conditions

Gabriel Markovič, Daniela Kaposztásová, Zuzana Vranayová

Abstract—Permeability of infiltration zone is qualitative and quantitative prerequisite for infiltration of rainwater in infiltration facility. Permeability is represented by the infiltration coefficient k_f, which represent efficiency of infiltration facility, respectively ability of subsoil infiltrate incoming rainwater. So it is always necessary to consider from the view of local conditions about suitability of proposed drainage concept. The main goal of this article is to show how depend an infiltration efficiency of percolation facility to infiltration coefficient k_f in real conditions.

***Keywords* —** drainage, percolation, rainwater, runoff, shaft.

I. Introduction

EVERY building and paved surfaces must be designed and constructed with a surface water drainage system. This drainage system must ensure the disposal of surface water without threatening the building and safety of the people [12]. Suitability of choice of type of infiltration facility is dependent on local conditions [4]. It is necessary to take into account the principles of design of these facilities, for example separation distance from buildings, groundwater level, infiltration coefficient etc. Therefore, in each case, it is to be considered carefully, which drainage concept in combination with the percolation of precipitation is ecologically sensible, technically possible and economically justifiable [5].

This work was supported by the VEGA 1/0202/15 Sustainable and Safe Water Management in Buildings of the 3rd. Millennium and APVV-SK-CZ-2013-0188 Lets Talk about the Water – An Essential Dimension of Sustainable Society of the 21.Century.

The Centre was supported by the Slovak Research and Development Agency under the contract No. SUSPP-0007-09.

Ing. Gabriel Markovič, PhD., Technical University of Košice, Faculty of Civil Engineering, Institute of Architectural Engineering, Vysokoškolská 4, 042 00 Košice, mail: gabriel.markovic@tuke.sk

Ing. Daniela Kaposztásová, PhD., Technical University of Košice, Faculty of Civil Engineering, Institute of Architectural Engineering, Vysokoškolská 4, 042 00 Košice, mail: daniela.ocipova@tuke.sk

doc. Ing. Zuzana Vranayová, PhD., Technical University of Košice, Faculty of Civil Engineering, Institute of Architectural Engineering, Vysokoškolská 4, 042 00, Košice, e-mail: zuzana.vranayova@tuke.sk.

II. Important design principles for correct design

A. Distance from buildings

It always should be respected a minimum distance from buildings, basement of the buildings and the average amount of groundwater levels. These dimensions can vary from a few decimetres to several meters. Figure 1 and 2 represent minimum distance from buildings. The same rules apply for underground infiltration facilities.

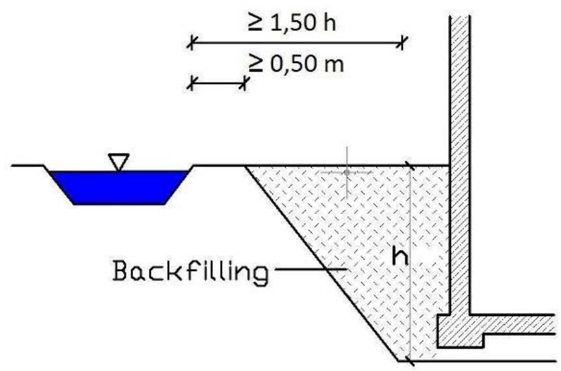

Fig. 1. The minimum distance of the decentralized infiltration facilities from building without waterproofing [6]

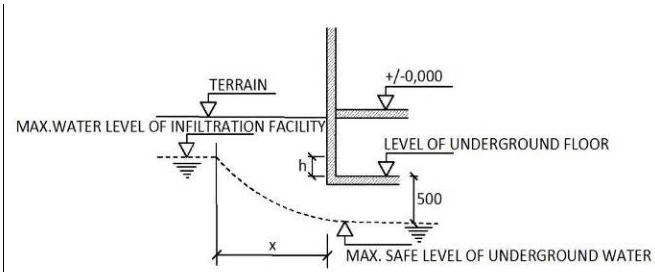

Fig. 2. Required separation distance from buildings [13]

Recommended minimum distances from the infiltration facility:

- 5 m from residential buildings without waterproof
- 2 m from residential buildings with waterproof
- 3 m from local vegetation (trees, bush etc.)
- 2 m from the property line, public communication, etc

- 1,5 m from gas pipelines and water pipelines
- 0,8 m from power lines
- 0,5 from telecommunication lines
- 1 m from ground water level

B. The permeability of infiltration area

The most important design parameter of infiltration facilities is to determine the infiltration coefficient k_f in the interest area, respectively infiltration coefficient of the soil where is planned to place an infiltration facility. Infiltration coefficient k_f generally represents an efficiency of infiltration facilities, respectively infiltration capability of the soil to absorb inflow water.

Permeability of the infiltration zone is a main qualitative and quantitative requirement for rainwater infiltration. Permeability of loose rock depends primarily on the size and distribution of the particles and compactness, in soils is critical soil structure and water temperature and is given by the infiltration coefficient. Permeability of loose rock varies in general between 1.10^{-2} and 1.10^{-10} m/s (figure 3). The k_f values apply to the process of infiltration water in the saturated zone. The range of values for the filtration coefficient for technical drainage ranges from 1.10^{-3} and 1.10^{-6} m/s [14].

The k_f values greater than 1.10^{-3} m/s cannot be reached for rainwater runoff and low depth of groundwater level the sufficient pretreatment through chemical and biological processes. If the k_f values are smaller than 1.10^{-6} m/s, the percolation facilities are loaded very long time. For this reason, anaerobic processes in the unsaturated soil, which resulting in adverse effects on retention and capacity capabilities of the soil can occur.

Therefore, the most important design parameter of the infiltration facilities is to determine the filtration coefficient k_f on-site.

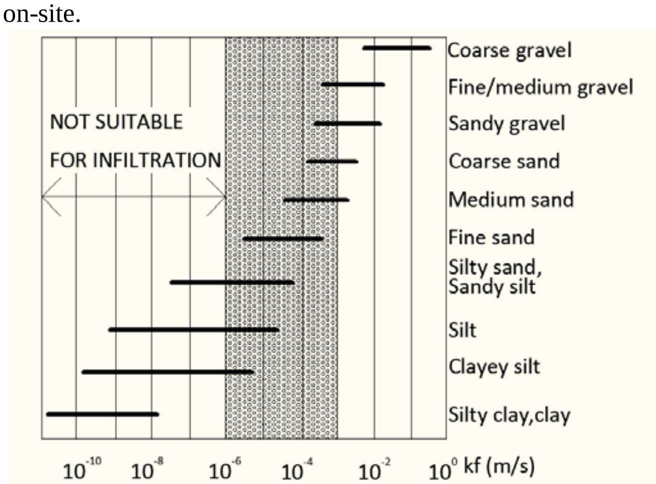

Fig.3 Recommended values of the infiltration coefficient

III. RESEARCH OF INFILTRATION EFFICIENCY IN REAL CONDITIONS

A. Experimental research in the campus of TU Košice-city

We have started our research and own measurements in scope of stormwater quantity and quality parameters at the campus of Technical University of Košice within the project relating to the management of stormwater. The objects of research represent two infiltration shafts in the campus of TU Kosice that were made before the start of our research. These infiltration shafts represent drainage solution for real school building PK6 and all of the runoff rainwater falling onto the roof flows into these underground shafts (figure 4) [1].

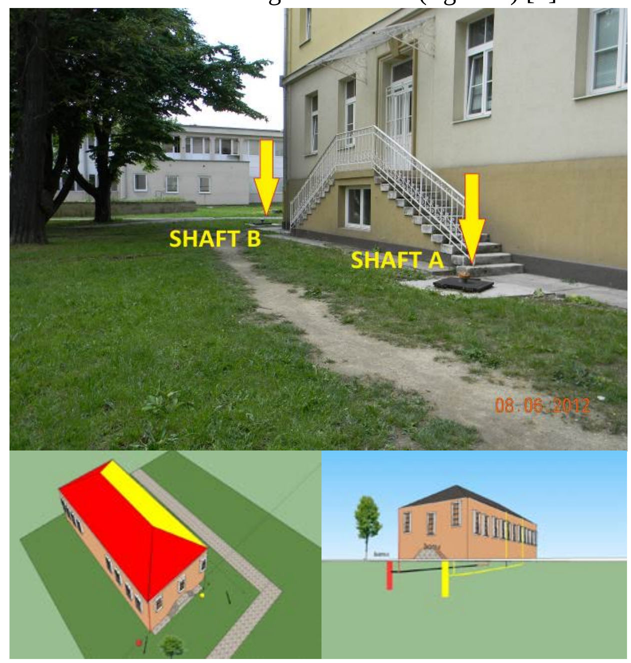

Fig.4 Location of drainage shafts near the PK6 building [2]

Tab. 1 Parameters of infiltration shafts [2]

	SHAFT A	SHAFT B
The outer diameter of shaft	**1000 mm**	**1000 mm**
The inner diameter of shaft	**800 mm**	**800 mm**
Shaft depth	**6,0 m**	**5,9 m**
Depth of inflow	**1,65 m**	**1,5 m**
DN of inflow pipe	**DN 150**	**DN 125**
Infiltration coefficient at the bottom	**1.10^{-3} m/s**	**1.10^{-3} m/s**
Drainage area of roof	**212 m^2**	**336 m^2**
Accumulation volume	**2,11 m^3**	**2,18 m^3**

The measuring devices for information about volume of incoming rainwater from the roof of the building PK6 and also information about the quality of rain water are located in both infiltration shafts [1]. All devices are connected with registration and control unit M4016. Unit M4016 automatically sent measured and archived data into the server database (data hosting) via GPRS in regular intervals [8].

Under inflow, respectively rain outlet pipe in the shaft, there are measurement flumes for metering of inflow rainwater from the roof of a building PK6 in both of infiltration shafts. Rainwater from the roof of the building PK6 is fed by rainwater pipes directly into measurement flumes, which are placed under the ultrasonic level sensor which transmitting data of the water level in the measurement flumes to the data unit M4016 (figure 5). Water level at the bottom of shafts is measured by pressure sensors type LMP307 (figure 5) [2].

Fig. 5. Measurement devices - Data unit M4016 in shaft A, Measurement flume with ultrasonic level sensor, Pressure sensor LMP307

B. Experimental research in peripheral part of Prešov-city

Second experimental research of infiltration efficiency is located in Šarišské Lúky near Prešov-city. Rainwater infiltration as a drainage solution is from bridge road after its reconstruction [10]. The infiltration gallery from infiltration units was designed in the monitored area by theoretical calculation.

Bridge object (Figure 6) is located on road 1/8 between Prešov and Kapušany. Approached two-way road on the bridge contains 4 lanes. It is bridge road over the train and local road MK Sekčov and road III/06815. Roadway on the bridge has one-sided slope 1,5% [7].

Existing bridge is made of prestressed concrete units, type I 73, cross – section 115/40, length 30 and 36 m, 15 pieces in cross section. Upper bridge length is 237.80 m, width between borders is 18.0 m [3].

Water from bridge was drained with water separators 250x500 to chamber which was emptied into sewer system. There were 24 pieces of water separators located on the left side of bridge, and 2 pieces of water separators located on right side next to excessive support structures. During reconstruction of bridge, existing water separators were removed. New water separators were embedding into the right side of origin places that ends above the ground. Rainwater drainage was built on left side by line drain canals. There are four lines of drain canals on the bridge object with outfalls to discharge rainwater pipes and next to the infiltration gallery.

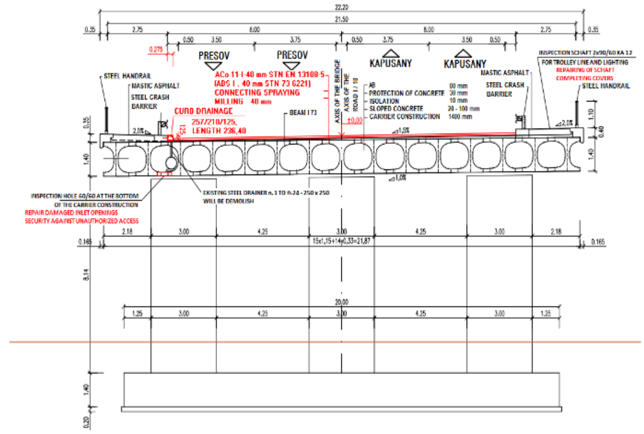

Fig. 6. Bridge object

Figure 7 shows the location of measuring equipment and objects for research. Rainwater from the bridge flows into filter shaft (1), which serves for capture and sedimentation of coarse and fine impurities. The rainwater subsequently flows into the infiltration gallery (2), where the water is filtered during infiltration to the soil. Measuring devices for volume of rainwater are the same as in infiltration shaft in campus of TU Kosice. A flow meter is located in the filter shaft, which record incoming rainwater in l/s. The water level in the infiltration gallery can be monitored by means of the float-gauge which is located in inspection shaft (3). Near this infiltration gallery is located rain-guage (4).

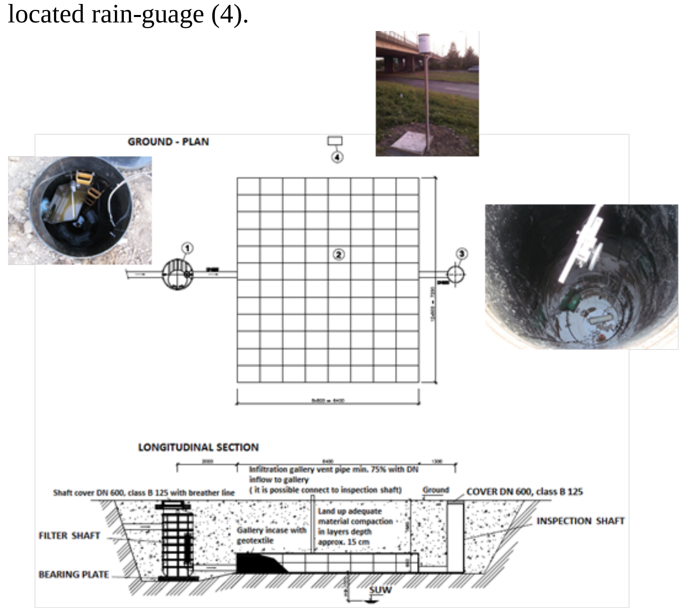

Fig. 7. Infiltration gallery – situation [9]

IV. Measurement and Evaluation

A. Experimental research in the campus of TU Košice-city

As was already mentioned above, the most important parameter of design not only for infiltration shafts, but in general infiltration facilities, is to determine the infiltration coefficient k_f in the interest area.

Morphology of the interest area is formed by alluvial plains of the river Hornád. The surface of the site is formed from anthropogenic sediments (fills). Under this layer are located fluvial sediments of river Hornád and under this layer are sediments of neogene age [15].

The fills of the interest area consist mostly of gravel clays, a building waste and natural gravels. Through the exploratory bores was to verify the thickness of these fills from 0.5 to 0.6 meters. Under the fills were verified fluvial sediments of the river Hornád. Immediately under the backfill was verified continuous layer of clay with a thickness of 4.0 to 4.5 meters. Under flood sediments were verified fluvial gravel sediments with a thickness of 5.0 to 7.0 meters, and its gravels blended with fine-grained soil. The bottom layer consists of clay-gravel with a thickness of 0.7 to 2.7 m (figure 8) [15].

Validation of the hydrogeological survey of the site, respectively verify the infiltration coefficient k_f of the soil in studied infiltration shafts near the PK6 building was made by taking samples of soil from the bottom of the infiltration shafts. Through the laboratory tests, the samples were evaluated as gravel blended with a fine-grained soil and infiltration coefficient set at 10^{-3} m/s, what confirming the hydrogeological survey of the site made for object Technicom in the campus of TU Košice.

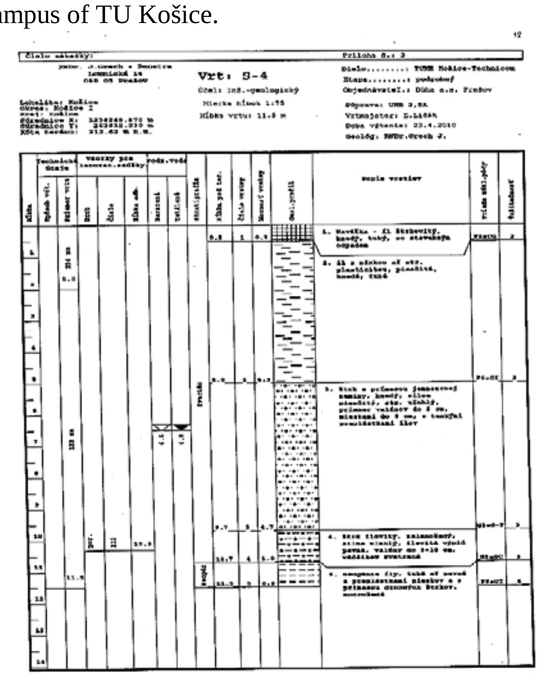

Fig. 8 Geologic cross section of interest area [15]

B. Theoretical calculation of infiltration shaft efficiency

Theoretical analysis of infiltration shaft efficiency respectively of the time required for infiltration of inflow rainwater from the roof of the building was processed for the studied infiltration shaft A and its real dimensions:

Locality: Campus TU Košice, PK6 building

- A_{imp} – area of roof for shaft A: 212 m^2
- d_e – outer diameter of shaft: 1,0 m
- d_i – inner diameter of shaft: 0,8 m
- k_f – infiltration coefficient: 1.10^{-3} m/s
- $r_{D(0,5)}$ – rainfall intensity for duration D and frequency n

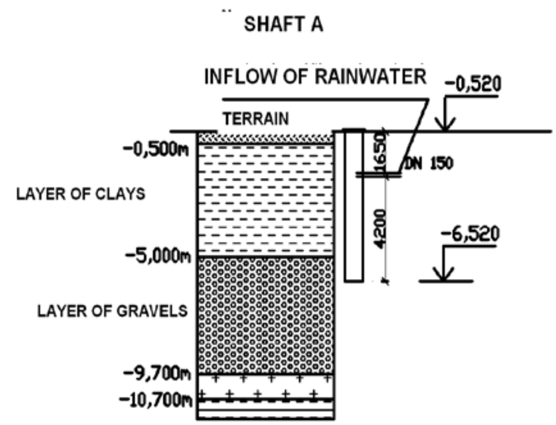

Fig. 9 Infiltration shaft A near building PK6 with geologic cross section

The calculation was processed for a range of infiltration coefficients from 10^{-2} m/s to 10^{-7} m/s for presentation as infiltration coefficient depends for design of infiltration shaft resp. facilities.

As a result from theoretical calculation (table 2, figure 10), the efficiency of infiltration shaft respectively time required for infiltration of rainwater inflow in studied infiltration shaft would be ranges of minutes.

It should also be noted that the infiltration coefficients suitable for infiltration by infiltration facilities ranges between 10^{-3} m/s to 10^{-5} m/s.

Tab. 2 Required time for rainwater infiltration in shaft A depending of the infiltration coefficients from theoretical calculation

Infiltration coefficient	**Rainfall intensity**	**z (shaft depth in m)**	**V (accumulation volume in m^3)**	**t (time of infiltration in hours)**
$k_f = 10^{-2}$	$r_D(0,5)$	0,32 m	0,16 m^3	t = 0,05 h
$k_f = 10^{-3}$	$r_D(0,5)$	2,97 m	1,49 m^3	t = 0,13 h
$k_f = 10^{-4}$	$r_D(0,5)$	7,51 m	3,77 m^3	t = 1,4 h
$k_f = 10^{-5}$	$r_D(0,5)$	12,47 m	6,26 m^3	t = 14 h
$k_f = 10^{-6}$	$r_D(0,5)$	14,46 m	7,27m^3	t = 143 h (6 days)
$k_f = 10^{-7}$	$r_D(0,5)$	14,73 m	7,40 m^3	t = 1432 h (60days)

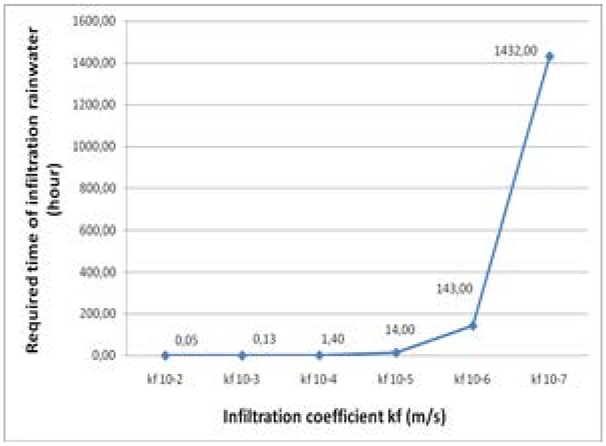

Fig. 10 Graph of required time of infiltration rainwater depending of the infiltration coefficient

Figures 11-16 represent typical process of flow rate and next percolation of rainwater during rainfall events in percolation shafts [3,10]. Figures 11-16 shows 4 selected rainfall events from year 2011 to 2014 with high rainfall intensity. All data from research show, the total infiltration of runoff inflow into the infiltration shafts from roof of PK6 building take place at the same time of duration of rainfall events, respectively very short-time after. This represents a high infiltration rate of this infiltration shafts. It is given by the coefficient of infiltration of soil at the bottom of shaft determined as $k_f = 1.10^{-3}$ m/s.

If we compared size of area for infiltration of runoff with other types of infiltration facilities (for example infiltration units) this size is several times smaller against another types of infiltration facilities. But the infiltration coefficient of surveyed infiltration shafts $k_f = 1.10^{-3}$ m/s ensures percolation of rainwater in required time so represents safe disposal of surface runoff for the object PK6 [11].

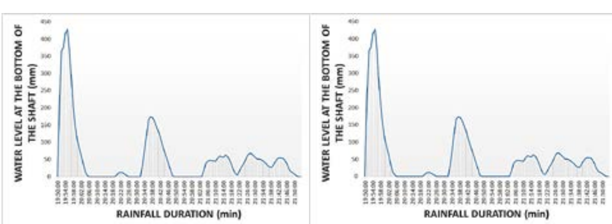

Fig. 11. Volume flow rate and water level changes at the bottom of shaft A during rainfall 14.9.2011

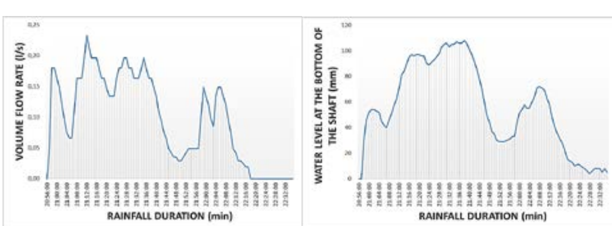

Fig. 12. Volume flow rate and water level changes at the bottom of shaft A during rainfall 24.4.2012

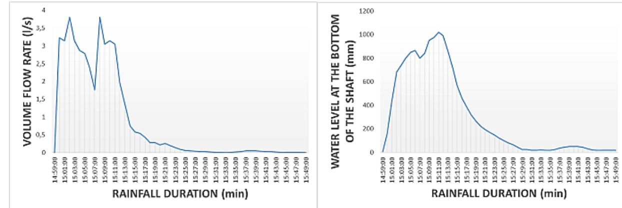

Fig. 13 Volume flow rate and water level changes at the bottom of shaft A during rainfall 30.7.2013

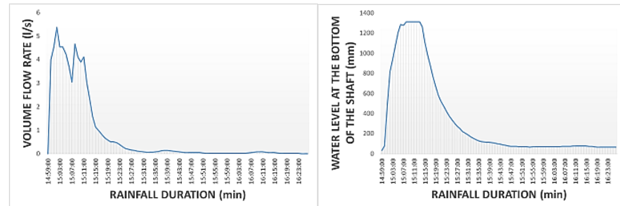

Fig. 14. Volume flow rate and water level changes at the bottom of shaft B during rainfall 30.7.2013

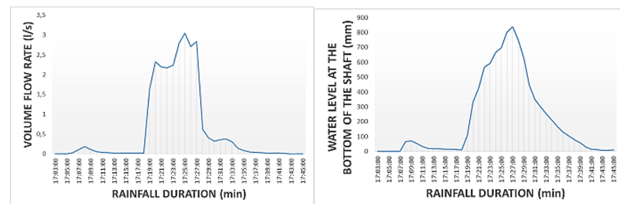

Fig. 15. Volume flow rate and water level changes at the bottom of shaft A during rainfall 10.6.2014

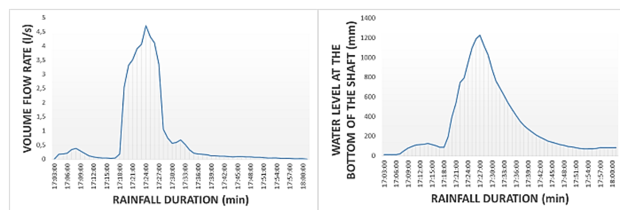

Fig. 16. Volume flow rate and water level changes at the bottom of shaft B during rainfall 10.6.2014

The maximum water level at the infiltration shaft A, measured during the research period 2011-2014 is 1,28 m, which is less than 1/3 filling depth of infiltration shaft A and maximum water level at the infiltration shaft B, measured during the research period is 1,31 m, which is less than 1/3 filling depth of infiltration shaft B too.

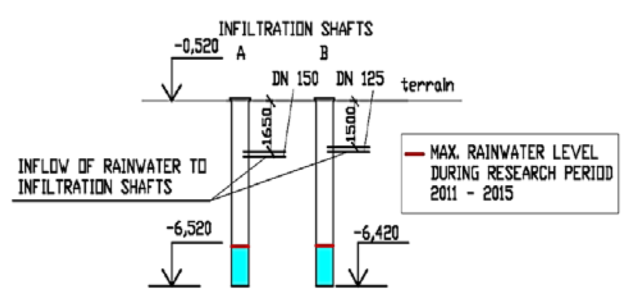

Fig. 17. Infiltration shaft and maximum water level during the research

C. Experimental research in peripheral part of Prešov-city

The percolation gallery is formed by plastic units. Infiltration block is made from strong polypropylene.

Infiltration block parameters are 0.60 x 0.80 x x0.33 m (length x width x height). Each blocks may be put in more layers and so create infiltration gallery with huge capacity on smaller surface. Depending up on proposed conveyor duty and friction angle of surrounded soil it is possible to put modules to the depth of 7.10 m below the ground level. The percolation area of the infiltration gallery is 46,08 m^2. Its surface is rectangular. The volume of rainwater draining into infiltration gallery and water level changes at the bottom was monitored with devices in the filter shaft.

Design of infiltration facility was without geological survey and geological data was only estimated. During the design phase of the infiltration gallery the infiltration coefficient was estimated by designer as $8{,}2.10^{-5}$ m/s. Infiltration facility was designed according German standard DWA - A 138 and all parameters of infiltration gallery were calculated with this infiltration rate which should ensure a sufficient and suitable percolation characteristics for this facility.

But results from laboratory test set infiltration coefficient in area of interest as $4{,}84.10^{-7}$ m/s! It means about 100 times lower infiltration efficiency and also lower accumulation volume of infiltration gallery as was design for safe disposal of rainwater runoff. This results to insufficient infiltration rate of this percolation gallery. Infiltration coefficient $4{,}84.10^{-7}$ m/s represents practically impermeable type of soil not suitable for infiltration facilities. Unfortunatelly this inaccurate design caused flooding and silting all infiltration gallery and result to failure of installed devices for research – figure 18.

Table 3 contain measured data of rainwater volume flow rate respectively theoretical calculation of required time for infiltration only one rainfall event. As a result from theoretical calculation (table 2), the efficiency of infiltration gallery respectively time required for infiltration of rainwater inflow of one rainfall event in studied infiltration gallery would be ranges of hours respectively in days.

Tab. 3 Calculated coefficients of hydraulic conductivity in Prešov

Date	Time from	Time to	Volume of rainwater [m^3]	Required time for infiltration [hour]
2.4.2013 4.4.2013	22:52	3:46	1,72	28,9
1.2.2013 28.2.2013	1:48	22:35	6,99	668,3
30.1.2013 31.1.2013	3:00	23:51	1,27	44,8
15.1.2013 16.1.2013	11:10	14:51	3,15	27,6
15.12.2012 19.12.2012	18:56	16:30	1,4	93,2
1.11.2012	10:40	23:02	0,12	12,3
19.9.2012 20.9.2012	19:49	15:51	3,07	20,03

Fig. 18. Flooded filter shaft with measurement devices

Figures 19-20 represent a starting point of measurements of rainwater percolation in infiltration gallery respectively water level in infiltration gallery. Next figures 21-23 represent typical process of rainwater percolation in infiltration gallery respectively water level in gallery during the month. Data from research showed that there was continuously high water level in percolation gallery. This represents a very low infiltration rate of this infiltration gallery what is given by the coefficient of infiltration of soil at the bottom of gallery determined as $k_f = 4{,}84.10^{-7}$ m/s and also means overfill of percolation gallery (figure 21-23).

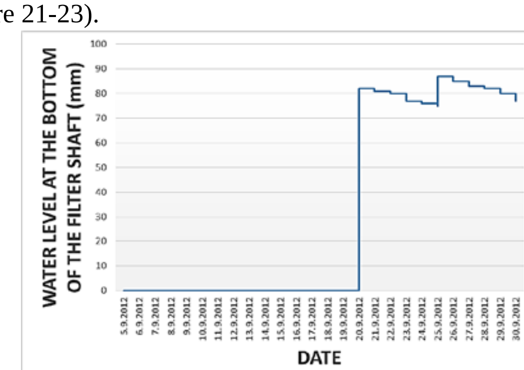

Fig. 19. Water level changes at the bottom of filter shaft during September 2012

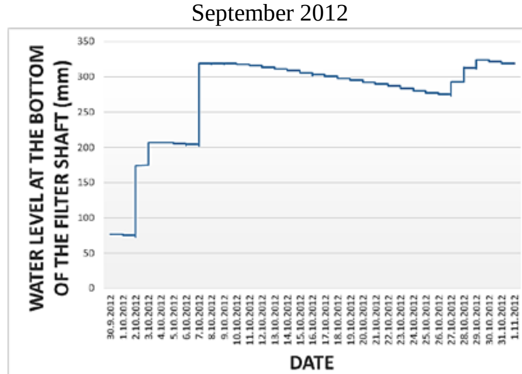

Fig. 20. Water level changes at the bottom of filter shaft during October 2012

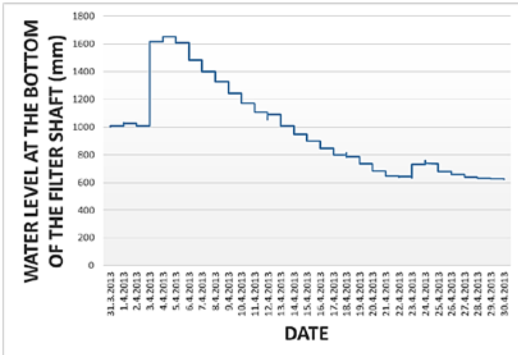

Fig. 21. Water level changes at the bottom of filter shaft during April 2013

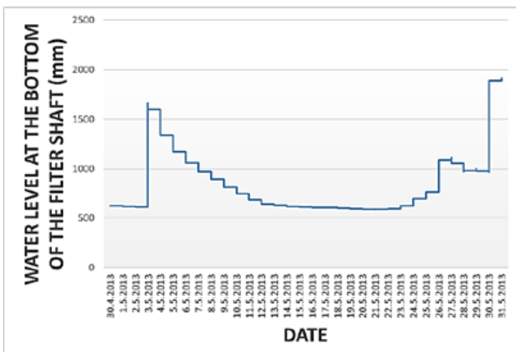

Fig. 22. Water level changes at the bottom of filter shaft during May 2013

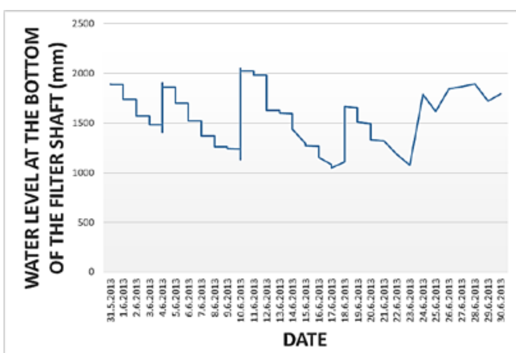

Fig. 23. Water level changes at the bottom of filter shaft during June 2013

V. Conclusion

Percolation drainage systems are technical solutions that provide an alternative to the traditional direct channelling of surface water through networks of pipes and sewers to wastewater treatment plant or watercourses. But these systems must be designed with regard of threatening the building and safety of the people.

As was mentioned above, suitability of type of infiltration facility is dependent on local conditions. Of course, it is necessary to take into account the principles of design of these facilities, for example separation distance from buildings, groundwater level, infiltration coefficient etc. An important prerequisite for infiltration is hydro-geological survey, which is often restricted to a minimum or only to the finding of data from maps and hydrological data. In this study, the results obtained through the research on the percolation facilities, demonstrated how coefficient of infiltration depend to efficiency of percolation facility in real conditions. So for correct operation of these facilities its necessary has knowledge of hydrogeological conditions in site of design.

Future research of rainwater infiltration systems should focus on development of a legislative framework for the design and operation of rainwater infiltration systems and the continuing to in situ research of effectiveness of infiltration facilities in terms of long-term operation in real conditions.

References

[1] G. Markovič, Z. Vranayová 2013 Infiltration as a means of surface water drainage, Košice: TU

[2] G. Markovič, D. Kaposztasova, Z. Vranayová 2014 The Analysis of the Possible Use of Harvested Rainwater and its Potential for Water Supply in Real Conditions, WSEAS Transactions on Environment and Development. Vol. 10, p. 242-249.

[3] M. Zeleňáková, P. Purcz, I. Gargar, H. Hlavatá, " Research of Monthly Precipitation Trends in Libya and Slovakia," Proceedings of the 2014 International Conference on Environmental Science and Geoscience (ESG '14) p.46, March 15-17, 2014, Venice, Italy

[4] A. Bucur, J. L.López-Bonilla, "An Approach to the Quality of Drinking Water as a Matter of Multicriterial Decision, Recent advances in energy, environment, ecosystems and development (EEED '13), p.43, July 16-19, 2013, Rhodes island, Greece

[5] H. Raclavska, J. Drozdova, S. Hartmann," Municipal Waste Water Toxicity Evaluation with Vibrio Fisheri, "Recent advances in environment, energy, ecosystems and development (EEEAD 2013), p.226, September 28-30, 2013, Venice, Italy

[6] DWA-A 138E: Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water, 2005.

[7] Technical report – I/18 Šarišské Lúky bridge reconstruction (in Slovak) No.18-449. Prodosing s. r. o., Bardejovská 13, 080 06 Ľubotice, 2012.

[8] Technical documentation Fiedler-magr – Manual M4016.

[9] M. Zeleňáková, G. Rejdovjanova, The importance of hydrogeological and hydrological investigations in the residential area: a case study in Presov, Slovakia - 2014. In: Infraeko 2014: 4 International Conference of Science and Technology : 29-30 May 2014, Krakow. - Rzeszow: Politechnika Rzeszowska, 2014 P. 319-325. - ISBN 978-83-7199-937-2

[10] M. Zeleňáková, P. Purcz, I. Gargar, H. Hlavatá, M. M. Portela 2014 Statistical Trends of Precipitation in Chosen Climatic Station in Slovakia and Libya, WSEAS Transactions on Environment and Development, Vol. 10, p. 298-305.

[11] G. Markovič, M. Zeleňáková, D. Kaposztasova, G. Hudakova, Rainwater infiltration in the urban areas - 2014. In: Environmental Impact 2. - Southampton : WITT press, 2014 Vol. 181 (2014), p. 313-320. - ISBN 978-1-84564-762-9 - ISSN 1743-3541

[12] P. Stahre, (2006): Sustainability in Urban Storm Drainage, Planning and examples, Svenskt Vatten, 81 p.

[13] Z. Žabička, "Technical solutions of infiltration facilities", in Proceedings of 15th International Conference Sanhyga, Piešťany, Slovakia, October 14-15, 2010.

[14] J. Vrána, (2010), "Design of infiltration facilities in Čzech Republic", in Proceedings of 15th International Conference Sanhyga, Piešťany, Slovakia, October 14-15, 2010.

[15] The final report of geological survey for object Technicom – Campus TU Košice, 2010.

Gabriel Markovič is researcher at the Faculty of Civil Engineering, Technical University in Kosice. He is specialised in Water supply and drainage systems. Recently he has been concentrated on the field of rainwater harvesting and rainwater infiltration systems.

Daniela Kaposztasova is lecturer at the Faculty of Civil Engineering, Technical University in Kosice. She is specialised in Water supply and drainage systems. Recently she has been concentrated on the field of hot water distribution systems and rainwater reuse.

Zuzana Vranayova is the professor at the Civil Engineering Faculty, Technical University in Kosice, Department of Building Services. She is conducting various researches on her major field of study of water supply and drainage system in buildings. She is also actively involved in governmental and academic institutions and committees related to her field of study as chief coordinator and board member. She is a vice dean for education