Infiltration and exfiltration from sewer network with a focus on house connections in city of Prague

I. Princ* and D. Kohout*

* Czech Technical University in Prague, Faculty of Civil Engineering, Laboratory of Ecological Risks in Urban Drainage – LERMO, Thakurova 7, 166 29 Prague 6, (E-mail: princ@lermo.cz , kohoutd@lermo.cz)

Abstract

Sewer systems constitute a very significant patrimony in European cities. Their structural quality and functional efficiency are key parameters to guarantee the transfer of domestic and industrial wastewater to treatment plants without infiltration or exfiltration.

The paper shows analysis several damages occurring on the house connections, their causes and influence on the amount of infiltration water to sewer system by HC or exfiltration of wastewater from HC to environment. Further is concern of obtaining the data and statistical evaluation and determination approach of infiltration and exfiltration amount.

Keywords

damages, exfiltration, house connections, infiltration, sewer system

INTRODUCTION

House connections are often the most neglected components of the whole sewer system. Results of a research in the USA [1] show that they may contribute to as much as 50% of total infiltration of groundwater. Exfiltration from leaky house connections can be substantial and of grave importance in terms of protecting groundwater against pollution as well as preserving foundations of buildings.

The topics of infiltration and exfiltration to and from house connections are included in the project entitled “Assessing Infiltration and Exfiltration on the Performance of an Urban Sewer System – APUSS”. This project forms a part of the Fifth Framework Programme of the European Union, and is divided into three work areas covered by 12 work teams. The project has brought together 10 partners in 7 European countries

OBJECTIVE

The objective is to assess and quantify the volumes of groundwater entering to the house connections (infiltration) and the volumes of wastewater leaking from house connections (exfiltration). Quantification of infiltration and exfiltration is based on field measurements on experimental sites as well as on a physical laboratory model. Another aim of the project is to develop new measurement methods to be tested on local catchment and verified on larger catchment of several cities.

Another outcome of the whole APUSS project is to develop decision-making support for administrators and operators to assess the performance of their sewer systems and to choose investment strategies for rehabilitation and repair.

THE INFILTRATION ISSUE

Ballast water comprises all groundwater entering the sewer system through infiltration, i.e. seeping from the surroundings (mostly subsoil) into damaged sewers or house connections via crevices, apertures or leaking joints in places below the level of groundwater or near substantial escapes from water supply pipes; these are classified as diffuse sources of infiltration. Another type of infiltration is from local limited sources such as brook mouths, drainage systems, water reservoirs or fountain overflows, or cooling water. This latter group of sources of infiltration was not classified under ballast water until recently, since the design of urban drainage applied the so-called Horler formula, appearing with slight variations in the regulations of the vast majority of European countries. Ballast water can be classified by time-dependent occurrence – by regular and irregular flows.

The objective of urban drainage is full collection of all wastewater and the fastest possible drainage from the urban basin. The drainage must not pose a threat or cause limits to inhabitants and/or delivery of surface and ground water. All water requiring drainage from the urban basin is classified as wastewater. Wastewater includes refuse from households, industrial refuse, rainwater, snowmelt, drainage water, reservoir overflow, and surface and ground water drained into sewers irrespective of the degree of pollution thereof *(Horler Formula).*

This fact has resulted in construction of costly technological means of drainage and sewer systems conducting water with the minimum degree of pollution, from which followed drainage of vast volumes of water from urban areas and increased inflow into wastewater treatment plants, thus overloading the plants, something which caused deterioration of function of the plants.

This approach is gradually being replaced by a very different method:
"Only water with a degree of pollution corresponding to wastewater, and which can be processed by a wastewater treatment plant, may enter the sewer system. The sewer system must be protected from ingress of ballast water."

Rehabilitation work aimed at achieving a decrease in water infiltrated from surrounding subsoil concentrates mainly on the core sewers thus leaving the house extensions neglected in the majority of cases. Yet, in consideration of the share of house extensions in the total length of the sewer system (21 per cent of the length of the sewer system in Prague), there comes the question of the actual contribution of the house extensions to the volume of infiltration of ballast water. Curtis and Krutsch (1993), for example, in their study for the Sewerage Agency of Washington County, stated that their studied house extensions had as much as a 50 per cent share in infiltration of ballast water.

Conditions of Infiltration into House Connections:

- The level of groundwater is above or at least at the level of the house extension
- Subsoil around the extension is sufficiently permeable
- Existence of a point of infiltration – damage of sewer piping (leaky joints, crevices, etc.)

Infiltration of ballast water increases the demand on the capacity of sewers and water treatment plants. Low temperature and dissolution of wastewater have a negative impact on the efficiency of the biological cleansing processes.

Field Measurements of Infiltration

A particular experimental site of infiltration of groundwater into sewers is in city district Prague 4 – Hrncire. The district comprises a newly constructed residential area with unfavourable hydro-pedological conditions.

The groundwater level in Prague-Hrncire is very high, often only 0.5 metres below the surface. This groundwater is the source of infiltration into the sewer system, gravitational in part, and succeeded by a vacuum sewer. A camera-assisted survey revealed infiltration of ballast water through house connections, in particular through house connections No.2 in Babockova Street (*Figure 1*), and extension No.1 behind pit No S6.

The discovery of actual points of infiltration and the plausibility of conducting a measuring of this small basin made it possible to attempt assessment of the volume of infiltrated water as bilateral

ingress into horizontal drainage of the above specified extensions and compare the calculations to the measurements.
For constant flow, the infiltration per unit of length of the drainage pipe can be expressed as follows:

$$q = K \cdot S \cdot I \tag{1}$$

where K is the factor of hydraulic flow ($m.s^{-1}$). For the given location, the value of the coefficient is approximately $K = 1.10^{-5}$ $m.s^{-1}$
S is surface area for unit pressure, corresponding to unit of length of the drainage (m^2)
I is pressure gradient corresponding to constant pressure level (1,0)

The next calculation will assume that the floor of the drainage element, in our case the sewer extension, rests on an impermeable layer, that the groundwater flow q is constant at the distance of x from the house connections on both sides per length unit, and that the external source of water is in the subsoil.
The differential formula is as follows:

$$q = 2Ky\frac{dy}{dx} \tag{2}$$

Integral to the above formula is the limiting of values of x = 0 and y = depth of water in the extension (this depth is negligible). This produces the final formula for infiltration flow into the house connections:

$$Q = 2K\frac{h^2}{R}L_p \tag{3}$$

where h is the difference between the non-lowered level of groundwater and the floor of the extension, set at 0.6 metres
R is the radius of lowering of the level due to infiltration of groundwater for the given soil set at 5 metres
L_p is the actual length of the house connections, lengths are 19.75 m and 22.40 m respectively. (*Figure 1.* – HC 1 and HC 2)

The calculation according to formula (3) yields values of infiltration Q_1 = 1.71 $l.min^{-1}$ and infiltration Q_2 = 1.94 $l.min^{-1}$, respectively, giving a sum of 3.64 $l.min^{-1}$. These values can be compared to the value of the daily minimum, which can be considered as a good approximation of extension infiltration. Recorded the daily minimum flow in sewers was Q_{Dmin} = 2.75 $l.min^{-1}$ (one week observation) with flow data available every ten minutes (*Figure 2*).

Conclusion

The method of calculation of infiltration into the house connection is based on an analogy with infiltration into horizontal drainage, the calculation being based on the Darcy Filtration Law. In this case the result is close to values of the daily minimum flows. It must be borne in mind that application of this calculation has its limitations. In case of the calculation being applied to systemic drainage, it is assumed that the drainage piping is perforated in uniform fashion along the whole length and that the drainage system comprises parallel and equidistant drainage pipes. It must be emphasised that the points of infiltration into sewers are leaky joints and/or crevices, i.e. apertures of variable size and variable distribution along the length of the piping, while the water inflow seldom follows the Darcy Law, the sources often being scattered where the Bernoulli formula applies, as in an example of infiltration from a waterlogged cavern. Further research should concentrate on verification of potential application of the drainage theory for approximation of infiltration of groundwater into sewer systems based on knowledge of the mutual position of the sewer, the level of the groundwater, the permeability of surrounding subsoil, and the actual condition of the sewer system.

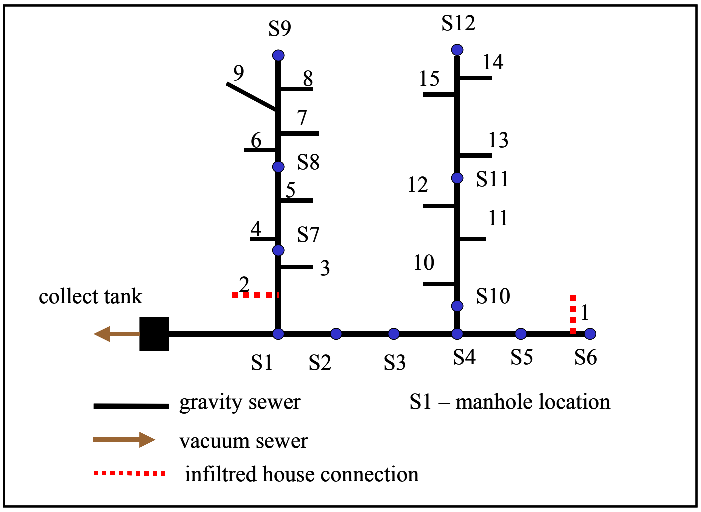

Figure 1 Sewer system scheme.

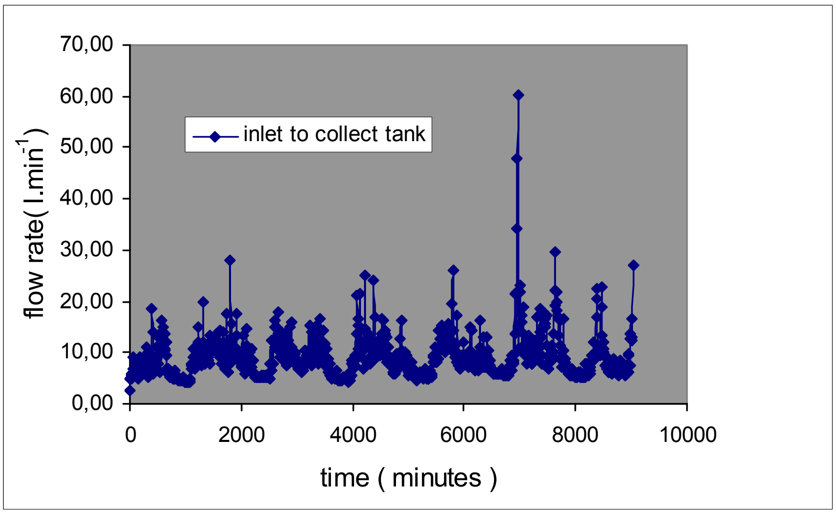

Figure 2 Inlet to collect tank recognized every ten minutes.

THE EXFILTRATION ISSUE

The main problem of the exfiltration issue is contamination of groundwater and springs as sources of water, including drinking water. Wastewater, which leaking from any type of damage pipe of house connections, run through the soil environment and directly threat human health.

From the constructional point of view, water flow in the soil environment continuously washes separate fractions of the soil, creating caverns threatening the stability of building foundations, municipal engineering networks and communications.

Outflow of wastewater from sewers causes an decrease of solid particles transport velocity and resulting faster pipe silting and increasing costs of sewer system maintenance.

Exfiltration Theory:

The guiding formula for exfiltration is expressed as a function of the hole outlet flow and flow through the soil environment [2].

The hole outlet for unsteady flow is $Q = f(t)$, Q and v is not constant:

$$v = \varphi \cdot \sqrt{2gh} \Rightarrow Q = \varphi \cdot \varepsilon \cdot S \cdot \sqrt{2gh} \qquad (4)$$

where φ is a velocity coefficient
ε is a coefficient of contraction
S is the cross-section area

Water flow in a variably saturated porous soil environment is defined (by Richardson):

$$\frac{\partial \theta}{\partial t} = div(K \cdot gradh + K_0) \qquad (5)$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K \cdot \frac{\partial h}{\partial z} + K\right) \qquad (6)$$

where θ is soil humidity
K is hydraulic conductivity (m/d)
h is head pressure (m)

Limiting conditions (maximum exfiltration):

- Total outflow from house: from all wastewater sanitary devices plus rainwater off the roof plus any illegal connections of drainage water
- Backflow of wastewater from the main sewer into the house connections (reflux stopper are recommended only)

Solutions to formulas (4) and (5) or (6) will give the volume of exfiltration; however, the theoretical results must be verified by measurements on a selected experimental catchment.

Conditions of exfiltration from house extensions:

- Groundwater table is below the house connections piping
- Damaged piping
- The house connections are installed on at least partially permeable backfill and in an unsaturated environment. Exfiltration does not occur with piping installed in impermeable backfill, such as clay. Exfiltration also does not occur in a completely saturated environment, e.g. after heavy rain.

TYPES OF DEFECTS AND THEIR CAUSES

First, a list of the most frequent defects and their causes was made, as they occur on house connections. A relation matrix was developed indicating insignificant and most significant defects that require attention. Mutual interactions are classified using a five-grade scale (with 1 being the emergency condition and 5 describing a small defect) and are used for specification of sequences of individual causes. The scale is similar to the assessment resulting from defects discovered during the camera-aided inspection (CCTV) in accordance with the standard ATV M143/2a.

Types of defects are the following: leaking joints (at socket, at manhole, at connection of the main sewer), a broken and loose pipe wall, obstacles (offset piping, tree roots, sediments, incrustation), cracks, corrosion, deformations. Causal factors are: level of groundwater in relation to piping, permeability of soil environment, type of material, age, traffic load, service life span, implementation, rainy or dry season aspect (*Figure 3*).

legend :

1	100%
2	75%
3	50%
4	25%
5	0%

		damages														factors	
		leakage joints			blocking				corrosion		cracks			others			
		bad joints	connections m. sewer	connections manhole	sediments	incrustation	roots	overlap pipe to m sew.	outside	inside	lengthwise	crosswise	radial	abrasion	deformation	average	order of importance
factors	high permeability	1	1	1	4	5	4	5	3	5	1	1	1	5	3	2,9	5
	med permeability	3	3	3	5	5	4	5	4	5	3	3	3	5	5	4,0	13
	material	2	2	2	5	5	4	5	5	5	3	3	5	5	2	3,8	12
	area	3	3	3	3	4	1	5	4	4	4	4	4	4	3	3,5	8
	rain	1	1	1	1	1	3	1	5	5	3	3	4	3	5	2,6	3
	life time	1	1	1	3	1	1	4	3	3	1	1	1	3	1	1,8	1
	maintainance	3	3	3	3	3	4	3	3	3	1	1	1	3	5	2,8	4
	implemantation	1	1	1	5	5	-	3	5	-	4	2	5	5	1	3,2	6
	aggressive backgroun	3	3	3	5	5	5	5	1	-	3	3	3	5	5	3,8	11
	aggressive water	4	4	4	4	1	5	5	5	1	3	3	3	3	5	3,6	10
	heavy traffic	1	1	1	5	5	5	4	5	5	1	1	5	5	1	3,2	7
	pulsating GWL	3	3	3	5	5	3	3	3	5	4	1	5	5	1	3,5	8
	ege	2	2	2	4	2	3	5	2	2	2	2	2	2	2	2,4	2
damages	average	2,2	2,2	2,2	4,0	3,6	3,5	4,1	3,7	3,9	2,5	2,2	3,2	4,1	3,0		
	order of importance	1	1	1	12	9	8	13	10	11	5	1	7	13	6		

Figure 3 Detailed matrix – example for exfiltration.

The most significant defect is at the joining of the house connections and the main sewer. That is caused by poor quality of installation of the piping, causing exfiltration. The subsoil backfill is insufficiently compacted with vertical loading (e.g. road traffic) resulting in compression of both pipes creating a gap. The use of ceramic pipes is advantageous due to higher resistance compared to PVC pipes.

Field Measurement of Exfiltration

The most suitable location for experimental measurement of exfiltration was found in the city district Prague-Troja. Based on information from local inhabitants a particular "problem-ridden" street was selected, where house-basements and water-supply manhole frequently get flooded from house connections as well as from the main sewer. The Prague Sewer Net administrator (PVK,a.s.) conducted a camera-aided inspection of the main sewer, including the house connections. The ascertained condition was classified as extended defects in several places, e.g. broken and loose pipe wall, gap in joint, etc.

The field measurement of exfiltration was conducted for a section of main sewer (demarcated by the inspection manhole M1 and the connecting inspection manhole M2), at a length of 46.1 metres, with ceramic pipe DN 250 mm, and with connections of two house connections DN 200 mm (*Figure 4*). The standard measurement method was applied, as in the case of water-tightness test. The experiment was commenced by blocking the lower end of the selected sewer segment with a sealing balloon at manhole M2 and filling the sewer segment with water to a specified level, followed by measuring the water level decrease at manhole M1 in time. The exfiltration rate corresponds to the lost volume of water in the given time, expressed as volume change ΔV at manhole M1 in time Δt. The resulting volume of exfiltration related to water level is indicated in (*Figure 5*). Measuring was repeated approximately after 20 minutes.

As the second part of experiment was sampling from water-supply manhole. Result of sampling analysis proved discharge of waste water from house connection to soil environment consequently to basement and manhole.

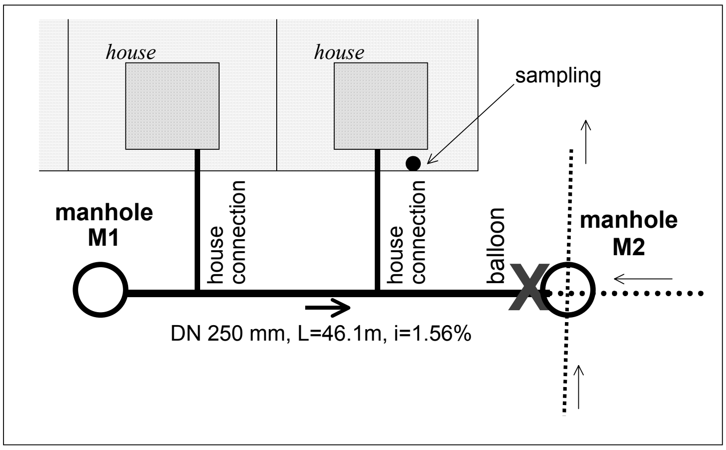

Figure 4 Layout of the experimental site.

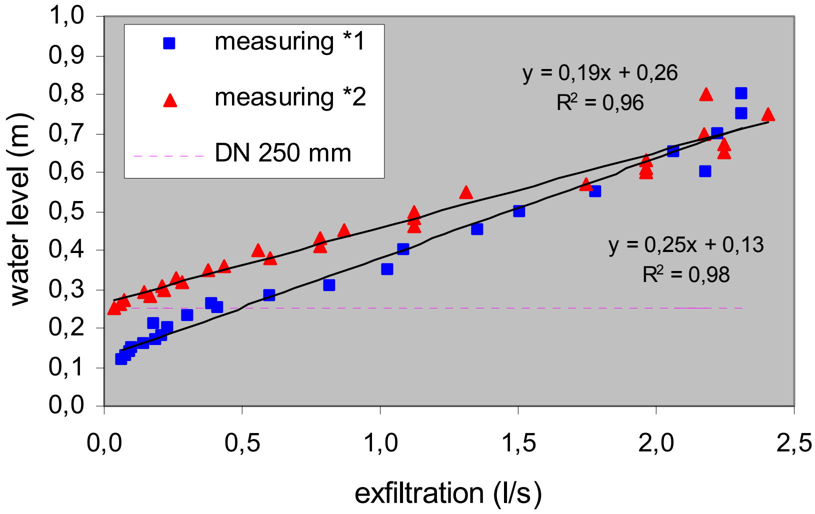

Figure 5 Exfiltration from sewer, observing water level in manhole M1.

The graph of exfiltration as shown on *Figure 4* indicates that outflow from the piping is directly dependent on the water level in the pipe *(h)*. With decreasing water level, the exfiltration volume drops. The outflow is also directly dependent on the filled volume of the system including house connections *(V)* under various water levels. That means:

$$Exf = f(h,V) \qquad (7)$$

In order to be able to compare measurements from various sites with different conditions (piping condition, type of backfill, etc.), the exfiltration level is expressed as a relative value, related, for example, to a length unit of piping, number of joints, or percentage of piping capacity. In the case of the experimental sewer in Prague-Troja, the following values apply: for a 75% filling of the DN 250 mm pipe the exfiltration rate is 0.23 l/s. The relative exfiltration rate related to 1 meter of piping is 0.0035 l/s, and the exfiltration rate related to the piping joint is 0.0034 l/s.

Conclusion

The performed measuring proved an undesired outflow of wastewater from the sewer (main sewer and house connections), which is damaged and in a condition that is causing ingress of water into basements and water-supply manhole.

The methodology of exfiltration measurement is based on standardised regulations applicable in the Czech Republic, regarding water tightness test of sewers. However, it has been adjusted for the conditions of damaged piping in operation. The most sensitive part of the method is in ensuring the tightness of the stopping up of the sewer with sealing balloons.

Examination of the infiltration/exfiltration issues of house connections requires the application of knowledge in the area of hydraulics, hydraulics of groundwater and transport processes in soil. It also requires execution of the taking of measurements of house connections and appropriate processing of obtained data.

Acknowledgements

This works was supported by the project of Ministry of Education, Youth and Sport of Czech Republic No. MSM 211100002, by the Czech Grant Agency project No. 103/01/0675 and EU – APUSS – EVK1 – 2000 – 22001.

List of references

1. WATER ENVIRONMENT FEDERATION: *Control of Infiltration and Inflow in Private Building Sewer Connections* (1999), Alexandria, VA (USA), ISBN 1-57278-160-2
2. CISLEROVA, M.: *Transportni procesy* (1998), ČVUT Praha, ISBN 80-01-01866-0 (in Czech)
3. CSN 756101: *Stokove site a kanalizacni pripojky* (1994), CNI Praha (in Czech)
4. HALOUN, R.: *Modelovani odtoku z intravilanu* (1993), ČVUT Praha, ISBN 80-01-00974-2 (in Czech)