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HISTORY, STRUCTURE AND DETERIORATION OF SEWERAGE SYSTEM IN WROCŁAW

The sewerage system is a vital component of all wastewater disposal structures. The architecture of buried municipal networks differs significantly depending on the considered city, local subsurface conditions and terrain configuration. History and characterization of sewerage system in Wrocław which is gravitational with pressure elements (pumping stations, pressure sewers) has been presented. The total length of gravitational sewers equals to ca. 1700 km, including 1300 km combined and separate sanitary sewers as well as 400 km storm water sewers under administration of Wrocław Municipal Water and Sewerage Systems Company only since 2010. The data about amount of wastewater and recorded failures of gravitational sewers in 2006–2008 have been collated and analyzed. The amount of wastes gathering by combined and separate sanitary sewers was equal to 43–47 million m^3 per year, and the average indicator of sewage effluent recalculated per one citizen of Wrocław agglomeration equaled ca. 0.178 m^3 per one day. On average per one month, the number of sewers' damages was in the range 7.3–8.3, and the average failure rate per one year and one kilometer of network length (without storm water sewers) equaled 0.07.

1. INTRODUCTION

Nowadays, according to strict environment protection regulations in Poland, it is essential to monitor the whole system of wastewater disposal structures. One of the most important components is sewerage system which connects each single household with wastewater treatment plant and protects the environment from the contamination accumulated in storm as well as in sanitary wastewater. Water supply and sewerage systems are fundamental for proper operation of the whole municipal management. Presently, the water systems are described precisely and a lot of investigations, concerning the flowability decrease and surface roughness increase [1], the reliability [2]

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and risk [3] management as well as operational safety [4] are done in Poland and abroad [5]. Unfortunately, sewerage systems are more difficult to inspect and describe because of lack information collected by municipal companies and more complicated domain of studies. However, in some Polish [6] and foreign cities [7] the investigations of deterioration of sewerage systems are carried out. Some failure frequency analyses of sewers were done in mining areas [8]. Also in Wrocław buried utilities are investigated [9], but rather from civil engineering and mechanical strength point of view. Still, there is a lack of inspections of sewerage system in Wrocław relating to typical matter of hydraulic and environmental engineering. That is why this paper discusses the infrastructure and deterioration problem of sewerage network in the years 2006–2008 in Wrocław in terms of failure types listed by Wrocław Municipal Water and Sewerage Systems Company (MPWiK) in its internal documentation which was made available because of bilateral agreement between Institute of Environment Protection Engineering and MPWiK [10].

2. BASIC INFORMATION ABOUT SEWERAGE SYSTEM IN WROCŁAW

Water and sewerage systems in Wrocław are the oldest in Poland. The privilege concerning water consumption and wastewater removal in Wrocław was given in 1272 by prince Henry IV. Till 1514 wastewater was dumped at the river Odra or Oława. Then the prohibition of dumping above water intakes was set. Wrocław Municipal Water and Sewerage Systems Company was established in 1871 when water for citizens was firstly purified on commercial scale. The design of sewerage system was signed in 1874. During the next seven years a combined system was built. Wastewater was pumped to sewage farms Osobowice and Dobrzykowice The total length of sewerage network at the end of XIX century was equal to 178 km. In XX century the system was expanded in the southern city districts and new intermediate pumping stations were built. Till 1930 the length of sewerage network increased to 423 km and at the beginning of World War II amounted to 838 km. Warfare caused much destruction of the sewerage system in Wrocław. Significant investments carried out in Wrocław could be specified as follows: the main interceptor called "North", the main interceptor called "Odra" and wastewater treatment plant "Janówek" (being in extension), pumping station "Nowy Port" as well as sewerage network for western and southern parts of the city. In the latter half of 2011 the extended wastewater treatment plant was put into operation, sewage farms will be unloaded and, in consequence, will be closed by reason of environment protection [11]. According to approximate statistical data, the population of Wrocław and neighboring districts in 2007 was established at the level of about 700 000 citizens. Sewerage system services not only the agglomeration of Wrocław, but also part of the parish Kobierzyce, village Wysoka, neighboring towns (which are situated closer to Wrocław than to other parishes) where wastes are removed to septic tanks and among others industrial plants like Cargil, Polmos, Wapko, 3M.

The framework of sewers is shown in the Fig. 1. The architecture of the network is complicated and widespread. Each city district has dense network of sewers, but in downtown, what is obvious, compaction is the highest.

Fig. 1. The framework of sewerage system in Wrocław [12]

The sewerage network in Wrocław consists of two types of systems (combined and separate – sanitary and storm water systems). The structure of underground infrastructure is shown in Table 1. The data in the table is overall and not detailed because of lack of full inventory control which is directly connected with permanent system developing and necessity of gathering only the most required findings. Especially during the last years, intensive development of sewerage network in some city districts, where in the past only septic tanks were used, is observed. Nowadays inspection of sewerage network is carried out only in some city areas but in the future the whole sewerage system in Wrocław should be inspected, using, e.g. TV methods, to establish more precisely the length, material, dimension of each single sewer section, intensity of damages and failure frequency which will be the matter of authors' scientific research. According to overall information obtained from MPWiK, the total length of sewerage network amounts to ca. 1700 km, which means that since Worlds War II the length was doubled because of urban development and including to administration storm water system. Generally, sewers in combined system are characterized by irregular cross-sections and their different modification (realized before World War II) like modification based on egg- and bell-shaped cross-sections. Thus it was difficult to determine which dimension is the smallest in irregular cross-sections. The whole system is made from various materials. Old sewers were built from typical materials as vitrified clay, brick, concrete, reinforced concrete; sometimes new materials are used presently, e.g. GRP, but according to MPWiK guidelines [13] rather typical and verified materials (clay, concrete) are preferred to use. Table 1 shows that wide range of dimensions is present in sewerage system in Wrocław. The largest dimensions occurred at the main interceptors "Odra" (3.5 × 2.8 m), "Bystrzyca" (1.4 m) and "Ślęza" (1.8 m). A typical diameter of house sewer is 0.15 m, but in some cases (when many buildings is connected to one pipe) the diameter could be larger, even 0.3 m. It should be pointed out that all information concern only the network which is under MPWiK administration.

Table 1

The structure of sewerage network in Wrocław

<table>
<tr><th>Sewerage system</th><th>Material of sewerage system</th><th>Length [km]</th><th>Cross-section</th><th>Range of dimension [m]</th></tr>
<tr><td>Combined</td><td rowspan="2">vitrified clay,
brick,
concrete,
reinforced concrete</td><td rowspan="3">1300</td><td>irregular: egg-shaped, bell-shaped, rectangular, pear-shaped, modification of all irregular shapes; regular: circular</td><td>Irregular:
no data
– 3.5 × 2.8.
Regular:
0.25–1.4</td></tr>
<tr><td>Separate sanitary</td><td rowspan="4">Circular</td><td>0.2–1.8</td></tr>
<tr><td>House sewer
in a sanitary system</td><td>vitrified clay,
PVC, GRP</td><td>0.15</td></tr>
<tr><td>House sewer
in a storm water system</td><td>vitrified clay,
PE, PVC</td><td rowspan="2">400</td><td>0.15–0.20</td></tr>
<tr><td>Storm water</td><td>concrete,
vitrified clay,
GRP, PE, PVC</td><td>0.2–1.6</td></tr>
</table>

Table 2 collates data on total amount of wastewater during considered period of time [14]. Only municipal wastes (sanitary and combined system) are included in the whole statement. Storm wastes from separate system are not taken into consideration. In the years 2006–2008, 29 intermediate pumping stations were in operation and pumped on average almost 62% of all wastes produced in Wrocław. The amount of pumped wastes was in the range 26–30 million m^3 per year. The rest of wastewater got the main interceptor "Odra" in a gravitational way. We have to remember that some infiltrated water or even sometimes water from unrecorded service pipes gets gravitational sewer and increases total amount of municipal wastes. On average per one year the efficiency of all wastewater treatment plants was equal to over 45 million m^3 and ranged from. 43 to 47 million m^3. During considered three years of operation, the number of wastewater treatment plants was equal to 5. Wastewater Treatment Plant "WOŚ (Janówek)" and sewage farms "Osobowice" and "Port" purified the majority of all municipal wastes. It is worth pointing out that in several months (after starting of extended plant "Janówek") sewage farms will be out of operation. Assuming that the number of citizens carrying away wastewater is equal to about 700 000, we can calculate the average and approximate indicator of sewage effluent (q_{ww}) per one citizen (NC) and day (d). For agglomeration of Wrocław and neighboring towns we can establish that

$$q_{ww} = 0.178 \ \frac{\text{m}^3}{\text{NC·d}}$$

Table 2

Amount of wastewater getting all treatment plants in the years 2006–2008

Wastewater treatment plant		Amount of wastewater, m^3/a		
		2006	2007	2008
Ratyń		131 648	158 435	176 977
Zakrzów		377 420	0	0
WOŚ		28 290 868	25 102 646	28 011 040
Osobowice		127 250	130 529	133 370
Port		18 999 512	18 462 898	17 060 000
Totally	sum	47 926 698	43 854 508	45 381 387
	on average	45 720 864		
Totally from pumping stations	sum	30 334 268	26 587 593	27 567 442
	on average	28 163 101		
Gravitational	sum	17 592 430	17 266 915	17 813 945
	on average	17 557 763		

3. DETERIORATION OF SEWERAGE SYSTEM IN WROCŁAW

Uniform systems of encoding and description of sewerage damages are necessary to make an assessment of proper sewer's operation. Many countries (e.g. Great Britain, Germany, France, Denmark) created their own definitions and classifications of sewer damages. Highly interesting review with remarks of seven the most important failure classifications was presented by Kuliczkowski [15]. After full analysis, the author showed advantages and drawbacks of each classification method. Such approach lets us choose the optimum method for considered wastewater removal system. The most known methods are quite descriptive and there is lack of precise technical specifications concerning the kind of damages, their causes and effects. Several years ago EU accepted unified notation system which is included in European Code EN 13508. From 2006, Polish version has been available: Polish Code PN-EN 13508. According to this code the sewer and inspection chamber damages are considered separately. In general, the Polish Code defines that failure exists when [16]:

- wastewater flow is blocked,
- frequency of overflow is higher than recommended,
- human health and life is endangered,
- receiving body of water is contaminated more than required in the regulations,
- other adjacent technical objects and infrastructure run risk of danger,
- the sewer construction is damaged,
- sewers are leaky,
- disagreeable odor occurs,
- operational access is difficult.

The obtained information about occurred damages were collected by Municipal Company (MPWiK) which interprets sewer failure as follows: *Sewer failure – sudden failure causing damages of road or building construction as well as partial or complete wastewater retention in sewer because of mechanical damage.*

Generally, definition of sewer damage, according to MPWiK, abstracts in few words the information included in the Polish Code. In this elaboration every kind of sudden event meeting specifications stated above is classified as sewer failure. But it is necessary to remember that the combination of each mentioned notation system could be in the future more useful to describe the deterioration of sewerage system in Wrocław or other cities and to plan the scheduled inspections.

The information about random events (understood as sewer failures) and number of these events at the sewerage network in Wrocław are listed in the Table 3, according to the documentation collected by repair teams in the time range 2006–2008. The damages were recorded during the whole 2007 and 2008, but in 2006 from February to June the damages were not recorded. Table 3 collects every kind of important data (including e.g. year, type of failure, season) connected with sewerage system deterioration during three years of analysis. Data about damages were recorded by repair teams after declaration from the city and also during planned pipe inspections. Identified and visible damages were eliminated using two different ways. The first option – O – MPWiK used own resources and equipment to eliminate the damage. The other – M – MPWiK commissioned the job to another company. This fact is quite important because shows that some sudden events such as e.g. cleaning and hook-wall packer inserting were easier and maybe cheaper to eliminate by external company. Sometimes several damages were repaired using both ways – O/M. There is lack of detailed information about kind of sewerage system and type of sewers' material. That is why

Table 3

Deterioration of sewerage system in Wrocław in 2006–2008

Year	Sudden failure	Number of failures			District of the city		Remarks	The way of failure elimination
		Winter period (3 months)	Summer period (4 months)	Total (7 months)	Winter period	Summer period		
1	2	3	4	5	6	7	8	9
2006	House sewer failure	3	6	9	A(1), D(2)	D(2), H(2), J(2)		O
	Road surface collapsing	2	0	2	A(1), H(1)	–		
	Sanitary sewer failure	0	5	5	–	A(1), E(4)	K0.2 and K0.25	
	Pipe–choking	0	4	4	–	D(1), G(3)		
	Sewer collapsing	2	3	5	G(2)	G(3)		
	Sewer failure in general – not precisely described	7	16	23	B(1), D(1), G(1), J(4)	B(1), D(2), F(1), G(6), H(1), J(5)		O/M
	Failure of inspection chamber	0	1	1	–	A(1)	rubble and soil at the depth of 4 m	O
	Wastewater required to be pumped	0	1	1	–	D(1)		M
	Sewer failure beneath the river	1	0	1	B(1)	–		O
	Lateral crack	0	1	1	–	F(1)		
Totally 2006		15	37	52	A(2), B(2), D(3), G(3), H(1), J(4)	A(2), B(1), D(6), E(4), F(2), G(12), H (3), J(7)		
Average failure frequency per one month		5.0	9.3	7.4				

Table 3 continued

1	2	3	4	5	6	7	8	9
2007	House sewer failure	12	14	26	A(3), C(1), E(1), F(1),G(1), H(1), J(4)	C(1), D(2), E(2), F(2), G(1), J(6)	connection with septic tank, kink of T-connection, pipe-choking, required precise localization, street flooding, collision with water pipe DN 150, TV inspection	O
	Road surface collapsing	5	6	11	A(2), B(1), J(2)	A(1), B(2), D(1), G(2)	TV inspection, leaky T-connection, surface collapsing near the inspection chamber	
	Sanitary sewer failure	2	4	6	D(1), G(1)	E(4)	damaged water pipe DN 250 – risk of water pollution	O
	Pipe-choking	1	4	5	A(1)	B(1), G(2), H(1)	–	O/ M
	Sewer collapsing	2	2	4	D(1), G(1)	E(1), J(1)	–	O
	Sewer failure in general – not precisely described	4	13	17	J(4)	A(2), E(4), G(1), H(2), J(4)	TV inspection, renewal of one fragment, damaged during the work of water repair team, renewal of T-connection	O/M
	Failure of inspection chamber	5	1	6	E(1), J(4)	G(1)	leaky inspection chamber – damaged pipes, bad technical condition, damaged inspection chamber – installed in combined system K 0.4, irregular height of funnel, repair of the bottom	O
	Combined sewer system failure	3	4	7	J(3)	A(1), J(3)	K0.25, K0.4, K0.3	
	Sewer elimination	0	1	1	–	A(1)		
	Lack of leak proofness	0	1	1	–	J(1)		
	Cleaning and hook-wall packer inserting	0	3	3	–	D(3)		M
Totally 2007		34	53	87	A(6), B(1), C(1), D(2), E(2), F(1), G(3), H(1), J(17)	A(5), B(3), C(1), D(6), E(11), F(2), G(7), H(3), J(15)		
Average failure frequency per one month		6.8	7.6	7.3				

Table 3 continued

1	2	3	4	5	6	7	8	9
2008	House sewer failure	10	20	30	A(3), B(1), C(1), G(1), H(1), J(3)	A(3), B(2), C(1), E(2), G(2), H(2), J(8)	damaged because of pressed pipe, damaged during the work of water repair team, pipe-choking, crack	O/M
	Pipe-choking	1	1	2	J(1)	D(1)	addition of sand from leaky T-connection – TV inspection	O/M
	Road surface collapsing	2	4	6	C(1), G(1)	G(2), J(2)	K0.25, K0.3	O
	Sewer collapsing	0	3	3	–	E(1), H(1), J(1)	–	O
	Sewer failure in general not precisely described	14	20	34	B(1), D(1), E(7), F(1), J(4)	C(2), D(1), E(3), F(3), G(2), H(4), J(5)	damaged concrete sewer K 1.0 between office building and primary clarifier, damaged during road repair	O/M
	Failure of inspection chamber	1	4	5	D(1)	G(1), J(3)	sewer crack near inspection chamber, lack of bottom, inspection chamber collapsing, leaky inspection chamber	O
	Combined sewer system failure	3	2	5	J(3)	G(1), J(1)	K0.25, K0.3	
	Storm water sewer failure after other operations	3	1	4	D(1), G(2)	F(1)	repair of street inlet after water pipe damage	
	Wastewater required to be pumped	0	2	2	–	A(1), E(1)	–	O/M
	Change a sewer	2	0	2	A(2)	–	–	O
Totally 2008		39	60	99	A(6), B(2), C(2), D(3), E(7), F(1), G(4), H(3), J(11)	A(6), B(2), C(3), D(2), E(8), F(4), G(8), H(7), J(20)		
Average failure frequency per one month		7.8	8.6	8.3				
Totally 2006–2008		88	150	238	A(14), B(5), C(3), D(8), E(9), F(2), G(10), H(5), J(32)	A(13), B(6), C(4), D(14), E(23), F(8), G(27), H(13), J(42)		
Average failure frequency per one month in 2006–2008		6.8	8.3	7.7				

the division of failure types in Table 3 was based on the assumption that if in the documentation was recorded precise information that the damage concerns e.g. sanitary sewers, it was assigned to failure of sanitary sewer. If, in the collected data, it is only information about e.g. pipe-choking without more precision, it was allocated to another event.

The whole year was divided into two periods: winter (from November to March – 5 months) and summer (from April to October – 7 months). The number of failures was considered separately because such failures as, e.g. pipe-choking are visible in the time of spring melting because of surface run-off carrying a lot of solids. But on the other hand in winter the necessity of changing one sewer section may occur more frequently. In each year the average failure frequency per one month is almost at the same level (Table 3). The average damages number per one month varied between 7.3 and 8.3. On average, in the whole considered period of time it was equal to 7.7. We have to remember that local climate in Poland results in quite low temperatures in winter and some sudden precipitation (snow and rain) also occurs very often. The work of repair teams is more difficult in winter due to e.g. frozen ground or thick snow coat on the ground surface. These facts cause that majority of running (planned) repairs is carried out in summer. Of course sudden catastrophic failures are repaired immediately after recognition, even when it snows.

Generally, during three years of operation, the total number of failure events amounted to 238. Analyzing only sanitary and combined system with the total length of ca. 1300 km (only since 2010 the storm water sewerage system is subject to control the administration of MPWiK), we can calculate average failure rate λ = 0.07 failure/(km·a). The reason for such deterioration is quite simple: year by year the pipe inspections concern more and more widespread city areas which is caused by more strict regulations of the condition of buried networks in Poland. It is connected with the European law which requires the highest operational reliability of environment protection infrastructure. On the other hand, some sewer damages (e.g. exfiltration caused by small slots or roots penetration) are not noticed for a long time (even for years) because they are not visible at the ground surface. This means that estimation of sewerage system deterioration is still incomplete and requires a lot of planned investigations using TV inspections or other techniques of scientific research which allow us to describe the failures as well as to apply the proper method of rehabilitation and damages prevention, which is carried out for several years.

During the analysis of sewerage deterioration in Wrocław, we should remember that the system quite old. The majority sewers were built before World War II. The rest was made in the 1970s or 1980s when workmanship quality was relatively poor. Nowadays, a lot of new sewer sections are being built year by year using European funds for improvement of protection engineering. The length of sewerage network in Wrocław has been increasing all the time and that is why it is extremely difficult to determine the total number of separate or combined sections. Besides, the problem with inventory control is still unsolved.

The main kinds of sewer damages (house sewer failure, road surface collapsing, sanitary sewer failure, pipe-choking, sewer collapsing, sewer failure in general – not precisely described, failure of inspection chamber) occurred in three considered years 2006–2008. Table 4 shows the total number of the most important damages without division into years.

Table 4

The main kinds of failures in the years 2006–2008

Sudden failure	Total number of failures
Sewer failure in general – not precisely described	74
House sewer failure	65
Road surface collapsing	19
Sanitary sewer failure	17
Sewer collapsing	12
Failure of inspection chamber	12
Pipe-choking	11
Totally	210

One third of all damages listed in Table 4, belongs to "sewer failure without precise description of the type". In the documentation collected by repair teams no exact information about kind of breakdown and the hindrances occurring during the random event were not recorded. In connection with it, under this notation is hidden every kind of damage and that is why the fraction is the highest. Nowadays, we try in Wrocław to achieve optimum solution concerning the planned inspections and the way of damage classification. It is seen in Table 4 that house sewers deteriorated also quite often, the most typical failures being choking, collapsing and work under pressure. The majority of all house sewer damages occurred in downtown what could results from the age, short distances between pipes and a lot of excavations. Also citizens' culture and bad habits should be taken into consideration. House sewers connect each single household with main sanitary sewers. Water consumer not only produces wastewater, but also throws to the sewerage system inadequate matter, e.g. rags and debris which cause choking or mechanical damages. Sewerage system users should be taught already in childhood what is permitted or forbidden. Only 11 times pipe was blocked, in general without information about the sewer type, which could be caused by throwing directly to the inspection chambers. It was also recorded that inspection chambers were damaged 12 times. The most typical failures of chambers were described as e.g. lack of leakproofness, collapsing and cracks. The rest of failures (28) are described separately because they occurred only in one or two years.

The event "wastewater required to be pumped" was recorded only once in summer 2006 and twice in summer 2008. The investigations showed that only once in 2006 the sewer beneath the river was damaged and lateral crack was recognized at one section of sewerage system. Because of totally improper operation one sewer was eliminated, once lack of leakproofness and three events of cleaning were recorded in 2007. In 2008, two sewer sections were eliminated because they were not necessary more to operate the whole sewerage system properly and four times storm water sewer was damaged after other operations. Combined sewer system was damaged 12 times in 2007 and 2008.

Table 5

Sewerage deterioration in dependence of the city district

District of the city		Year			Totally
		2006	2007	2008	
A	South	4	11	12	27
B	South-East	3	4	4	11
C	South-West	0	2	5	7
D	West	9	8	5	22
E	North	4	13	15	32
F	North-East	2	3	5	10
G	North-West	15	10	12	37
H	East	4	4	10	18
J	Downtown	11	32	31	74
Totally		52	87	99	238

Deterioration of the sewerage system in the city differs in dependence of the quarter because used materials or age of the system are different. Thus Wrocław was divided into nine districts as shown in Table 5. Information concerning deterioration in each district are quite overall, not detailed because the area and the length of network in each part of the city are not known. The highest number of failures occurred in downtown which could be caused by, e.g. high network compaction. The system in downtown in the majority was built before World War II as combined system made from vitrified clay and brick with egg-shaped cross-sections. Nowadays, especially in downtown, the road load is larger than in the past which causes higher deterioration. Presently, heavy rains occur more frequently and more often combined system is overloaded what results in flooding the streets and road surface collapsing. During three years of operation South-West part of Wrocław deteriorated 7 times. The cause is quite simple – the sewerage system in this city district was built recently. In other quarters the number of damages ranges from 11 to 37. Wrocław seems to be very vast city and also the buried infrastructure (material, age, type of system and workmanship quality) differs. The results from the whole city might be summarized as overall not detailed, but in future it will be necessary to make planned investigations (e.g. TV inspections every five years) in each single district separately to obtain more reliable results and conclusions.

4. CONCLUSIONS

- The sewerage system in Wrocław is one of the oldest in Poland. It is made of typical materials (vitrified clay, brick, concrete) and sometimes plastics. The total length of the network equals to ca. 1700 km.
- The approximate indicator of sewage effluent is equal to 0.178 m^3 per one day.
- Totally, in considered time period, 238 sudden failures were recorded. Average failure rate per one year and one kilometer of network length (without storm water sewers) equaled 0.07.
- The average failure frequency per one month varied between 7.3 and 8.3. On average, in the whole considered period of time it is equal to 7.7.
- The most damaged part of the network is downtown. The youngest system is in the South-West part of the town, where the deterioration is the lowest.

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