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Reliability and failure rate analysis of pressure, vacuum and gravity sewer systems based on operating data

Katarzyna Miszta-Kruk

Warsaw University of Technology, Faculty of Environmental Engineering, Department of Water Supply and Wastewater Management, 20 Nowowiejska Str, 00-653 Warsaw, Poland

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ABSTRACT

This paper presents an assessment of operational reliability of elements of pressure, vacuum and gravity sewer systems, based on research focused on 7 different systems. The article discusses both traditional (gravity) sewer systems and unconventional sewer systems that are implemented on a large scale. The analysis and assessment were based on the data collected during investigations of real sewer systems over a period of 3 to 5 years.

On the basis of the analyses, this paper presents the system elements that were found to be most susceptible to failure as well as the most common types of failure events. This analysis allowed the duration of the identified failure events to be determined and yielded a reliability assessment in the form of failure rates (λ) calculated for each highlighted element. An analysis of the results in terms of the functions of the objects most susceptible to failure allows one to assess their operational probability.

1. Introduction

Theories of network systems' reliability (including sewage disposal networks), but especially of water supply network systems, have been developed since the beginning of the '70s. Corresponding theories of risk and safety were developed in the mid-1990s.

In the world literature on the subject, and especially as relating to the reliability of water supply and wastewater disposal networks, these issues are to a large extent investigated as a result of activities of IWSA (International Water Supply Association) or AWWA (American Water Works Association). Generally, they focus on the assessment of reliability of water supply systems. This domain is better explored through investigations and development of particular theories. However, the intuitively comprehensive approach to this subject should cover an analysis of the reliability of wastewater disposal systems as well. Both systems together provide a comprehensive service of supplying water to and disposing of sewage from users.

Almost at the same time, as the start of reliability analysis of water supply systems [16,28,29], research efforts also began to focus on wastewater disposal systems. However, such evaluations were often treated as investigations of secondary importance. Only a few researchers, however, decided to face the challenge related to the assessment of the level of reliability of sewer systems. Among them, one could count the following: [1,3,4,7].

E-mail address: katarzyna_miszta-kruk@is.pw.edu.pl.

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Reliability of sewer systems is most often considered in terms of the need to dispose wastewater from users [3,5,6,8]. An intensive development of reliability theory creates a wide range of possible applications aimed at solving problems related to the design and operation of sewer infrastructures. Network systems constitute one of the typical arrangements where application methods are sought for [9].

In the case of sewer systems designed both as traditional solutions and as unconventional ones, it is also important to determine unequivocal criteria, in order to rationalize a reliability assessment. Relevant proposals can be found in the following publications: [2,4,11–15,3,6,10]. The methods proposed in the last three texts are used in practice to assess reliability of different network systems in Poland.

2. Structure of sewer networks under investigation

Pressure and vacuum sewer systems belong to so-called unconventional wastewater disposal systems. In pressure sewer systems, as in vacuum ones, the medium flow is forced by the pressure differential generated in small wastewater pumping stations or, in the case of vacuum sewer systems, by means of vacuum pumps. In this, they differ from gravity sewer systems (referred to as traditional), where the flow of sewage proceeds generally in partly filled conduits by the force of gravity.

Concepts of pressure and vacuum wastewater disposal appeared already by the end of the 19th century, when technological developments allowed engineers to construct devices to pump or draw sewage. At this point, it is worth mentioning, the first pressure sewer system in Poland was designed and constructed in 1899 in Olsztyn. At that time, the network serviced 93% of the town and disposed of about 3000 m^3 of sewage per 24 h [11,13]. The earliest functioning vacuum sewer systems reach back to the 1990s. The first wastewater collection system of this type was patented in 1888 in the United States by Adrian LeMarquand. It was called the system of wastewater collection by barometric depression [EPA/625/1-91/024 1991, 16]. This was the beginning of modern unconventional sewer systems. At present, such systems raise high interest as alternatives for gravity sewer systems.

It is advisable to implement unconventional sewer systems primarily in areas characterized by relatively dispersed development (single-family houses, village settlements, etc.) with small changes in altitude or flat areas. Both the pressure and vacuum sewer systems are especially applicable wherever sewage is intermittently generated, namely in camping sites, holiday centers, in the case of exceptionally poor soil and groundwater conditions, in protected areas or on the fringes of water reservoirs. Both pressure and vacuum sewer systems may also be implemented to collect wastewater in underground railway tunnels, underpasses from parking lots, in large industrial halls, construction sites, as well as to handle wastewater transmitted from ships in docks and from passenger airplanes or ships.

In the pressure sewer system, wastewater is transported under pressure generated by pumps. The system consists of the following elements: chambers, controlled pumps, and networks of pressurized conduits with accessories. The pipes of a pressure sewer system, as opposed to sewers of a gravity sewer system, are laid at a constant depth below the lower frost penetration limit (about 1.2 m) and it is not necessary to ensure their proper inclination gradients. A pump may force wastewater for the distance of up to several kilometers and up to the height of 45 m · wc. A receiver chamber allows wastewater to enter another sewer system or constitutes the last element before wastewater enters a wastewater treatment plant. The goal of this system is to carry wastewater from internal installations of buildings and facilities in a given area to a point of wastewater disposal (a gravity sewer system or a wastewater treatment plant) (Fig. 1).

The vacuum sewer system operates by the force of a negative pressure (0.6–0.7 bar) generated by vacuum pumps in a pumping station. The negative pressure is transmitted to household collection chambers via conduits laid to assume a saw-toothed profile. At the moment of drawing wastewater and its associated mixing with the air in collecting chambers (fitted with discharge valves),

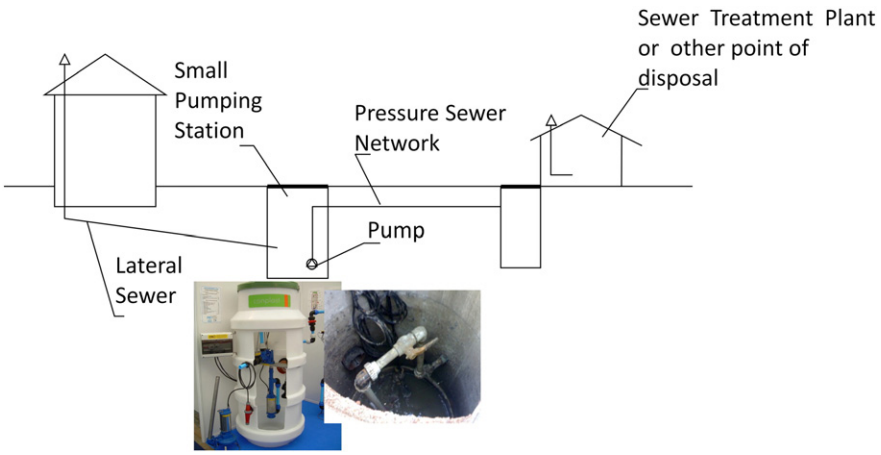

Fig. 1. Construction scheme of a pressure sewer system with identifying system elements.