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Risk of structural failure in concrete sewers due to internal corrosion

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ABSTRACT

The purpose of the investigations was to find out the frequency of internal corrosion occurrence in concrete sewers, the thickness of corroded walls, and to develop the method of determining the risk of structural failure due to corroded pipes.

The data on corroded concrete pipes were collected in CCTV (Closed Circuit Television) surveys performed at the Kielce University of Technology. The surveys covered the total of >14 km of concrete sewers operating in numerous locations in Poland's cities and towns. The frequency and the thicknesses of corroded pipes in sanitary, stormwater and combined sewers were established. The sewers, in which corrosion was observed, were classified into the proposed categories of structural failure probability which differed in sewer wall loss relative to the full thickness of the sewer wall. Additionally, the method was proposed for determining the category of failure consequences and the risk of sewer failure due to internal corrosion.

The results of surveys showed that, like in other countries, also in Poland, internal corrosion in concrete sewer poses a serious structural hazard to their safety. The proposed method gives an important tool that allows a proper management of sewer systems constructed from concrete pipes. The method makes it possible to eliminate, or significantly to reduce structural risk caused by internal corrosion in concrete sewers which can be done by scheduled CCTV surveys of sewers and trenchless renewal performed according to plans developed in advance.

1. Introduction

Most sewers in Poland, and in other countries, have been constructed from concrete and vitrified clay pipes. According to [1], concrete pipes make up 42% of all existing sewer pipelines in Germany. The total length of sewers in Germany is estimated to be approximately 600,000 km, thus the issues of technical condition concern about 240,000 km of concrete sewers in Germany alone. A similar share of concrete pipes in the material structure of sewers in service is found in other countries, including Poland, where in some cities concrete pipes account for more than half of the operating sewers.

Long operated sewers deteriorate over time [2,3], they may contain defects that pose structural and environmental hazards [4,5]. The defects observed are classified into two groups: structural ones, e.g. a missing sewer wall or longitudinal cracks, and operational ones, e.g. movable deposits or groundwater infiltration into the leaky sewer. The first group of defects also includes internal corrosion, analysed in this paper. The corrosion can be uniformly distributed over the inner surface of sewer walls, or its strongest attack can occur in the wetted cross-section with mostly partial or full filling, especially in the sewer crown.

Corrosion of concrete sewers can be internal [6,7] and external [7,8]. The mechanisms of internal corrosion in the sewer environment caused by hydrogen, sulphide, micro-organisms and other factors are discussed in many papers [9,10,11]. Corrosion is categorised as belonging to the group of primary defects [12]. Producing a decrease in the load capacity of sewers, it can cause secondary defects such as leak-tightness, cracks and fractures, deformations and collapse. It also leads to additional increase in the roughness of the sewer wall and causes a reduction in flow capacity.

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Many methods of forecasting the corrosion rate are available. This study [13] presents descriptions of a majority of those, including Schmitt, Pomeroy, Thistlethwayte and Hvitved-Jacobsen methods. Examples provided in many studies indicate that the actual corrosion rate differs considerably from the values calculated in accordance with those methods. For instance, the formulas used do not account for the effect of concrete class on the corrosion rate. In [14], a relationship between the corrosion rate and concrete class, not accounted for in the Pomeroy formula, was estimated on the basis of the analysis of 20,482.10 m of CCTV (Closed Circuit Television) – surveyed concrete sewers made of different concrete classes. It was proposed to introduce coefficient k_z into the formula. It would depend on concrete class and take the following values: 1.8 for C8/10, 1.5 for C12/15, 1.2 for C16/20, 1.0 for C20/25, 0.8 for C25/30, 0.5 for concrete formerly denoted as B35 (class between C25/30 and C30/37) and 0.2 for B40 (class between C30/37 and C35/40). An example of very fast corrosion was observed, among others, in pre-stressed C40/50 concrete pipes, 1400 mm and 1600 mm in diameter [15]. Although the sewers were operated for only 15 years, and the class of concrete was high, the corrosion observed was deep and equalled about 20 mm. In field measurements described in [7], a considerable impact on corrosion of the lack of natural sewer ventilation and improper longitudinal slopes of sewers was noted. Such factors are not accounted for in the formulas expressing the rate of corrosion processes, either. The following example can be used to illustrate the importance of the factors mentioned above. In combined sewer mainly of C35/45 concrete, without lateral connections or natural ventilation, in the sewer crown, about 90% corrosion was found, though it had been in operation for only five years. In contrast, in a very old (90 years), properly operated concrete sewer [7], no corrosion was observed. In [16], an example was provided of a sanitary sewer, with the diameter of 800 mm, constructed from C20/25 reinforced concrete pipes, which had been used for 40 years. After that time, corrosion affected the internal pipe wall only superficially, and, at the most affected place, it caused 8 mm thick loss in the structure. Also, in some places where the aggregate grains were coarser, the wall thickness was equal to the initial thickness of 90 mm. Conversely, another examined sanitary concrete sewer with the diameter of 200 mm, made from very low class concrete (C8/10), after 28 years in operation, showed pitting corrosion on the sides, over the whole thickness of the sewer wall, which revealed soil outside the external surface of the sewer.

The examples presented above, illustrating difficulties in the estimation of concrete sewer corrosion rate, confirm that it is necessary to check, on a cyclic basis, the technical condition of operated sewers with CCTV methods.

The aim of this paper is to give a quantitative analysis of internal corrosion observed in CCTV surveys conducted in sanitary, stormwater and combined sewers. The analysis is intended to establish the frequency and the magnitude of internal corrosion, reasons for which it occurred, and also to make categorization of internal corrosion. Five categories of the probability of structural failure due to internal corrosion were proposed. Categorisation criteria were established on the basis of recommendation given by [17]. In addition, categorisation of the consequences of structural failure caused by internal corrosion of concrete sewers was put forward, in which eleven different factors that affect those consequences were accounted for.

Another goal of this study was to recommend a strategy for the effective management of sewers with internal corrosion. It involves the determination of the risk of structural failure for each sewer in which internal corrosion is observed. The proposed method allows effective management of sewers by preventing their structural failure. That is done by sorting out priorities as regards trenchless renewal. The first concern is the sewers with the highest risk of structural failure, whereas for others, the rehabilitation work can be postponed. Renewal of sewers prevents the reoccurrence of internal corrosion in the future.

In all parts of the world, the rehabilitation of sewers with different defects, including concrete sewer affected by internal corrosion, generates huge costs. The application of the method proposed in this paper can contribute to reduced risks of structural failure caused by internal corrosion and, thereby, to savings on expenditure on sewer rehabilitation. Currently, [6,12,18,19] many trenchless technologies of sewer renewal (repair, rehabilitation and replacement methods) are available, which effectively protected sewers from internal corrosion occurrence for minimum 50 years.

2. Methods and materials

CCTV methods were used to investigate the occurrence of internal corrosion in concrete sewers. Currently, CCTV inspection is the most widely used method in surveys of the technical condition of sewers. The CCTV equipment was described, among others, in [20]. In CCTV surveys, measurements of the thickness of the corroded pipe walls were also taken, and the comprehensive strength of concrete used in pipes was checked in a non-destructive test.

At the Kielce University of Technology, CCTV surveys were conducted in many towns and cities throughout the country. The inspections started in 1991, and altogether, >200 km of sewers made of various materials (concrete, reinforced or pre-stressed concrete, vitrified clay, asbestos cement, steel, cast iron, PVC, PE, PP, and GRP) were examined.

The analysis presented in this paper covered 14,116.5 m of concrete sewers selected at random in 24 Polish towns and cities, including 7725.8 m of sanitary, 3031.4 m of stormwater and 3359.3 m of combined sewers. Four hundred and four sections of sewers were inspected, including 203 sanitary, 80 stormwater and 121 combined sewer sections. The diameters of the concrete sewer pipes varied from DN 200 to DN 800.

3. Theory

3.1. Methods of risk evaluation used in underground infrastructure systems

To develop the method of evaluation of the risk of structural failure caused by internal corrosion in sewers constructed from concrete pipes, an analysis of the existing tools of risk evaluation used for underground infrastructure was performed. Risk is an ambiguous concept. For some researchers, risk is equated with the probability of occurrence of a particular hazardous event. For