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EXAMPLE OF SEWERAGE SYSTEM REHABILITATION USING TRENCHLESS TECHNOLOGY

TECHNOLOGIE BEZWYKOPOWE JAKO PRZYKŁAD RENOWACJI SIECI KANALIZACYJNYCH

Abstract: The sewerage network in Poland, built in the early 20th century, has been losing its original water-tightness and flow capacity. To bring these characteristics back, rehabilitation works are performed. The initial capacity of sewers can be restored without affecting the urban environment thanks to the trenchless technology. The sewer subjected to rehabilitation receives a new internal leakproof layer capable of preventing groundwater infiltration as well as sewage leaks, which can contaminate the environment. This paper intends to compare the trenchless technology with traditional open cut trench excavation. In the study, two variants of trenchless rehabilitation were considered: one performed with the help of GRP panels and the other using cured-in-place pipe (CIPP) lining. Flow velocities and flow rates in the sewers before and after rehabilitation were compared. Also, selected economic and environmental aspects of sewer rehabilitation methods were examined.

Keywords: sewerage network, renovation methods, trenchless technology

Introduction

Sewerage network is a capital-intensive underground utilities in developing countries. Currently maintain of sewer lines is essential to guarantee proper transfer of sewage to the wastewater treatment. Low visibility of sewer systems cause that local governments often forgotten about the problem until sewers show major failure, ended with difficult and costly renovation [1].

Rehabilitation of sewers reduces infiltration of water into the system and thereby relieves sewage treatment plant, increases capacity of the sewer system [2]. Damaged sewer lines, especially the oldest combined sewers typically located in city centre with high historical or strategic meaning, require rehabilitation works. Closely populated and crowded urban areas forced the government to seek methods that appear to install and extending the life of existing underground networks. Lots of big cities need to renovate underground utility infrastructure systems. To meet this demand, governments began to accept trenchless technologies as a cost-effective and minimally invasive way to maintain underground networks [3]. Modern technic gives the opportunity for trenchless repair,

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which is characterized by reduced environmental impact. Trenchless technology is a new area of construction using advance methods, special equipment and materials used for the renovation or replacement of existing underground infrastructure with minimal or no need for open cut excavation. It is why we call it no-dig technology.

Sewerage systems in Poland, built several dozen years ago, have been losing their initial qualities, particularly their water tightness. The materials they were made of have been getting older. Moreover, sewage system was rarely cleaned. Continuous accumulation of sludge diminishes cross-sectional area of flow and thereby limits the carrying capacity of sewer pipes [4]. Its utilization included only basic repairs.

In 2003 Poland signed the Accession Treaty and committed to meet the requirements of European law. EU directives in the topic of the protection of the environment related to the introduction of higher standards of water and sewage quality discharged into water. Mostly European Council Directive 91/271/EEC [5]. Poland had to adjust the status of sanitary system to other EU members. So far repairing existing sewerage network was marginalized. Analysis of sewage systems showed insufficient or lack of wastewater treatment before discharged to the receivers and bad technical condition of sewer. Poland launched projects aimed at assessing and improving the technical condition of sewage channels.

That kind of problems with sewage system are experienced by other countries around the world. Slovakia has historical city centres and tries to avoid much integration in road traffic near the old building [6]. Malaysia has a problem with sewers collapsing but some local governments prohibit excavations. Trenchless technology was the only way to renovate the system [1]. China and United Arab Emirates using trenchless methods due to crowded cities [3, 7]. Delay in the road traffic bring high cost what case very serious problem for busy cities developing car transport. Rehabilitation of sewers in large cities is very expensive. Therefore, in order to reduce expenses, the replacement, renovation and operation of sewer lines are usually optimized.

Rehabilitation of sewers

Prior to the rehabilitation of the sewage channel, it is necessary to perform its diagnostics. Most sewer systems are inspected visually by mobile closed circuit television systems or human inspectors. For this reason it is important to seek new and developing sewer diagnostic techniques. The paper [8] presents a review of current technologies for inspecting brick, concrete and vitrified clay sewer systems, including the results of three experimental investigations. The results of the review are given in a tabular form that lists the applications, advantages and disadvantages of each technique. The problem analysis was based on sewer inspection work carried out for the City of Montreal. As sewer inspection methods was used: inspecting the inner sewer wall surface by mobile or stationary closed circuit television with computer assisted CCTV interpretation, laser based scanning systems, ultrasonic inspection (sonar). The authors conclude that more development work is required before other methods such as ground penetrating radar, microdeflections and the spectral analysis of acoustic waves come into common use as sewer inspection tools.

Rehabilitation of sewer systems is performed in three major steps including determination of current needs, choice of a proper rehabilitation option and finally, selection of the best technology [9]. The determination of urgencies requires estimating the hydraulic capacity of a given sewer stretch and evaluating whether the existing infrastructure meets actual requirements. The sewerage network should be adjusted to the shape of a built-up area, its population and the amount of water used for domestic and industrial purposes. The renovation project should assume at least another 50 years of trouble-free operation [9]. Determination the above-mentioned parameters and conducting a technical inspection both help to recognize whether the sewer line needs to be repaired, renovated or replaced (Fig. 1).

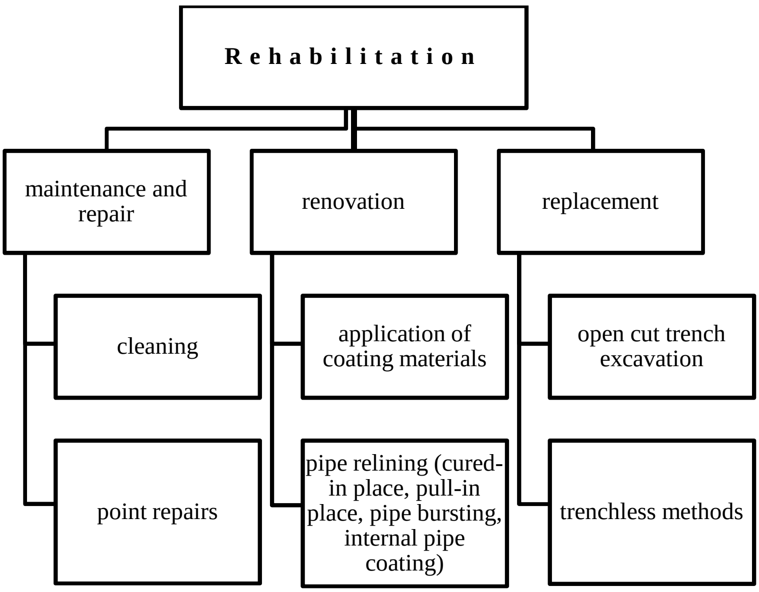

Fig. 1. Sewer system rehabilitation techniques [9]

Maintenance and repair are usually recommended for the sewers whose cross-sectional area has been reduced due to long-lasting deposition of sludge. Maintenance includes methodical control of the sewage flow characteristics and removal of blockages [9]. Local leaks can be fixed by point repairs. Renovation aims at removing repeat damages and leakages of complete sewer lines. Replacement is usually administered when serious damages occur and renovation is impossible or very expensive.

The choice of a proper solution should be made after careful consideration of the technical condition of a given sewer line, the type of material it was made of, shape and cross-sectional area of the pipe, the worksite and surrounding soil conditions, the type of transported medium, availability of specific technology and necessary expenses. The optimal solution can also be selected using diagrams offered by technical standards (Fig. 2) or available technical literature [10-12]. Selection of the optimal technology is the last step of the decision-making process, which should also include an overview of available methods, sewer parameters and surroundings.

There are limited documented criteria and specifications for condition assessment of sewerage and choosing appropriate rehabilitation technologies. Each of countries have own standards of sewerage rehabilitation [13] but there are only general assumptions.

Scientists are developing different optimization models for civil engineers to find an appropriate renovation strategy consisting of a rehabilitation method and a substitute material for each pipe failure under a limited budget.

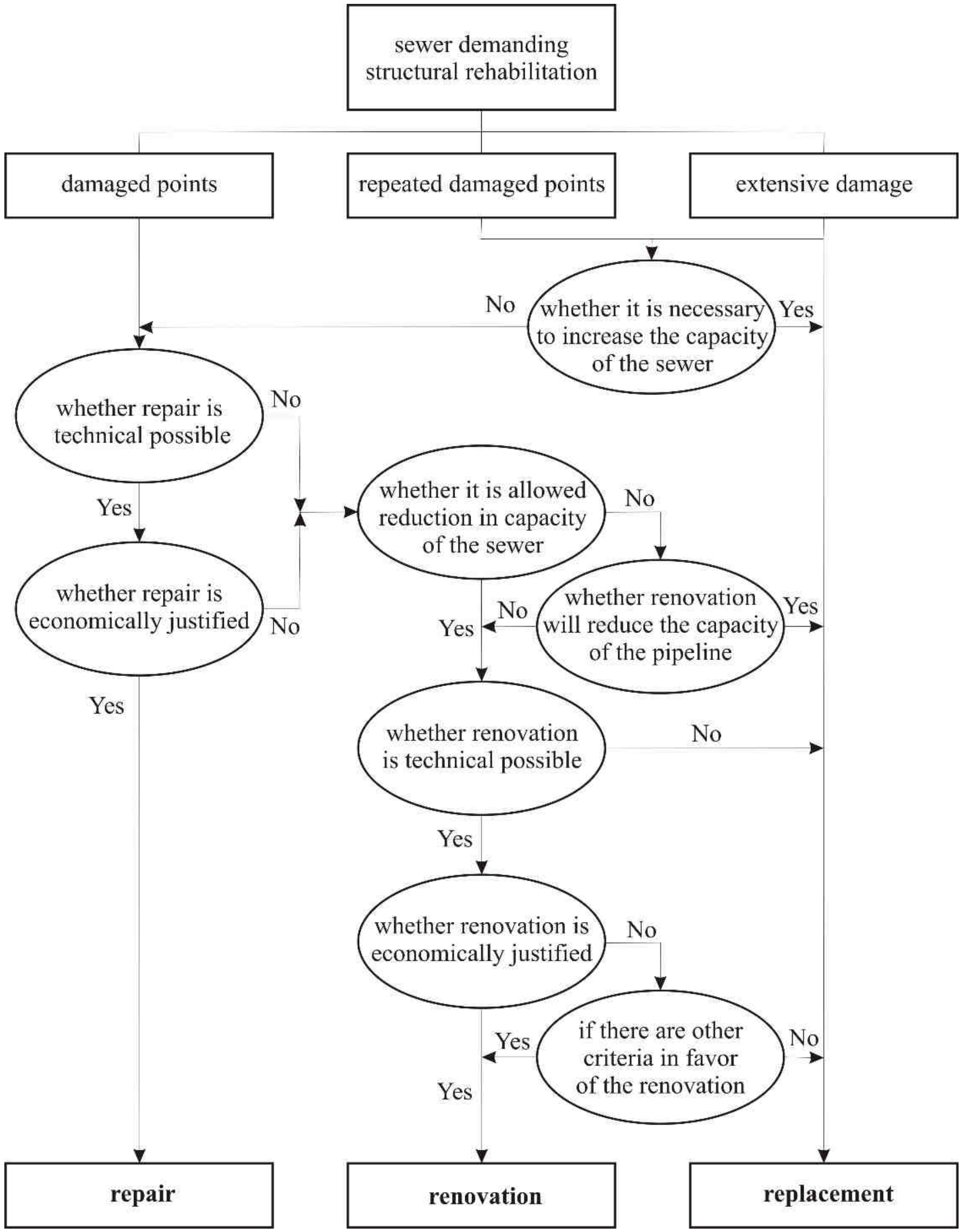

Fig. 2. Sequence diagram for the rehabilitation of sewer systems with reference to PN-EN 752-5 [14]

The research include surveys send to the company who perform rehabilitation of sewage. Special algorithms are created based on data like: age of pipes, material, localization (GIS), types of ground and budget. In example to find a Pareto curve used to define the optimal solution with indicated rehabilitation effectiveness using the lowest cost in Taiwan was designed an optimization model. It let saved about 20% of the rehabilitation expenses in city [15]. The exemplary optimization models are described in literature [16-18].

Equally important is the standardization of injury assessment. The goal of a standardized defect coding system is to create a common, comprehensive and reliable reservoir of data to assess the sewer pipeline. This data can then be used in the prioritization, planning, and systematic renovation of wastewater collection systems. Based on NASSCO’s Pipeline Assessment Certification Program (PACP) it is possible to determine: structural defects (cracks, fractures, broken, holes), operational & maintenance defects (deposits, infiltration, obstacles, obstructions), construction features (taps, intruding seal material, alignment, and defects not otherwise identified) [19].

Trenchless techniques vs. open cut trench excavation

The development of technology has enabled renovation of pipe networks with the use of trenchless techniques, resulting in reduced environmental impact. Rehabilitation works should be preceded by the analysis of economic and technical issues, expected social impact, ecological factors and legal regulations.

a) b)

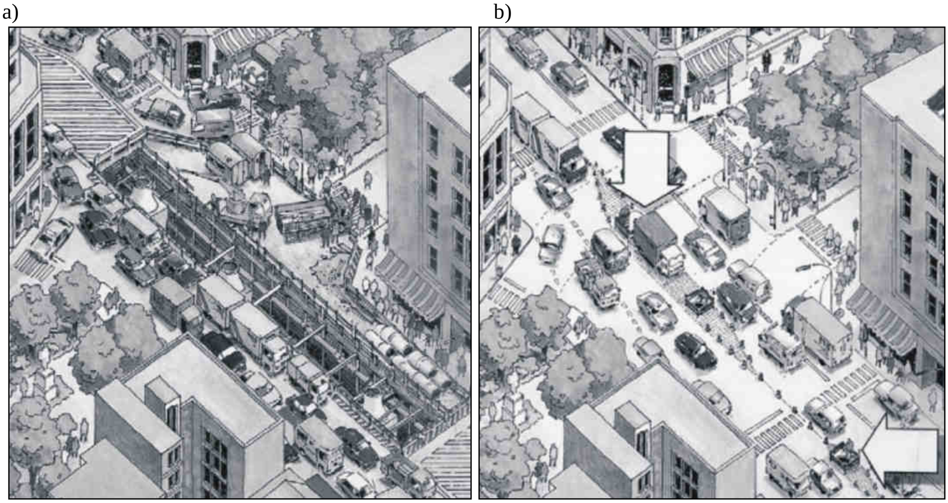

Fig. 3. The impact of renovation of underground infrastructure on the street with heavy traffic: a) using open trench method b) using trenchless method [20]

The economic analysis should consider the costs of excavation, dewatering, occupation of a traffic lane and road surface restoration. Using the trenchless technology can reduce these costs even by half [1]. Urban technical infrastructure is usually located under the road and pavement surface. In the case of trenchless methods construction sites do not have to be fully separated from automobile and pedestrian traffic as they are mostly confined to point excavations. In Figure 3 we can observe the difference between traffic jam during excavation and trenchless rehabilitation. Limitation of digging is associated with a reduction in the amount of land being removed. The transport of the soil is carried out by heavy trucks which cause noise and vibration of the area, often destroying road surfaces nearby.

Using trenchless techniques, paralyzing traffic jams and public annoyance can be avoided. Infrastructure repairs are extremely burdensome for residents. Difficulty in moving through the city cause the lengthening of travel time what is a nuisance and affects both motorists and pedestrians and cyclists. With the use of trenchless methods of renovation underground infrastructure, it is not necessary to build bridges crossing trenches for vehicles and pedestrians. Moreover the protests of owners of shops, restaurants, hotels and other services located in the vicinity of trenches, which often claim compensation for income reduction, are limited [20].

The use of trenchless methods is justified when sewer rehabilitation is planned to be performed at a greater depth in difficult soil or in the area where collisions with the existing underground utilities are possible. The trenchless methods are also recommended under railway tracks, watercourses, airports and landmarked buildings [1]. The use of trenchless rehabilitation methods eliminates the risk of incorrect location of sewerage in the ground.

The trenchless work requires much less time than open trench excavation, which helps guarantee meeting deadlines. On the other hand, the open trench work conducted in difficult soil can cause serious problems such as damage to the existing pipelines, deterioration in stability of the surrounding buildings and harm to urban greenery.

Moreover erosion leading to the contamination of water resource. Trenchless technology significantly reduce CO_2 emissions to the atmosphere, what could be the cause of health problems. Excavation method result in the pollution of soil [21-23]. Open-cut construction often require removing trees which is unnecessary in trenchless technology. Another thing is a noise pollution, which is harmful product of open-trench constructions [23].

Methodology

In this study, sewers rehabilitated with the use of different trenchless methods were compared with regard to their carrying capacity and flow velocity. The analysis was conducted using archival project data, sewer condition assessment data and post-completion documentation. It also included hydraulic calculations performed for worn out sewers containing sludge and the same sewers after renovation, but only sections between junctions were considered. Flow velocity v and flow rate Q were determined from Eq. (1) (Manning's equation) and Eq. (3), respectively. Manning's roughness coefficients were adopted according to [24].

$$v = \frac{1}{n} \cdot R_h^{\frac{2}{3}} \cdot i^{\frac{1}{2}} \tag{1}$$

where: v - flow velocity in the sewer pipe [m/s], n - roughness coefficient $[\mathrm{s} \cdot \mathrm{m}^{-\frac{1}{3}}]$, R_h - hydraulic radius [m], i - sewer bottom slope [-]

$$R_h = \frac{A}{U} \tag{2}$$

where: A - effective cross-sectional area of the flow [m^2], U - wetted perimeter [m]

$$Q = v \cdot A \tag{3}$$

where Q - volumetric flow rate [m^3/s].

For sewer system design, a self-cleansing velocity of at least 0.7 m/s is advised in order to avoid deposition of sludge at the bottom of the sewer. The maximum sewage flow velocity should be adjusted to the type of pipe. While designing a sewerage system, one also assumes that it is leakproof.

Renovation of man-accessible sewers using GRP panels

Glass Reinforced Plastic (GRP) panels are resin coatings reinforced with glass fiber. They are used to renovate sewers and drains of any shape: circular, oval, bell-shaped or parabolic. Renovation using GRP panels can be conducted regardless of the pipe material [25]. Modern GRP components are made of self-supporting materials and can be used in the case of sewer pipes not fully possessing this quality. The space between the inner surface of a pipe and the outer surface of the inserted module is filled with grout, which additionally ensures full stability of the construction. The panels are introduced through inspection chambers or specially prepared access points. The new coating has high chemical and abrasion resistance.

The analysis was conducted for a large-size oval-shaped sewer main J IV 0.90/1.60 m. The examined main was built around 65 years ago from clinker bricks bound by cement mortar. The aim of renovation was to extend its operating life for at least another 50 years. Rehabilitation of 1930 m of the sewer main was meant to improve its hydraulic parameters, restore its reserve capacity and eliminate groundwater infiltration. The works were carried out using GRP panels produced by Amiantit Poland Sp. z o.o. having a diameter of J 750x1400 [26]. The renovation process is illustrated in Figure 4.

a) b) c)

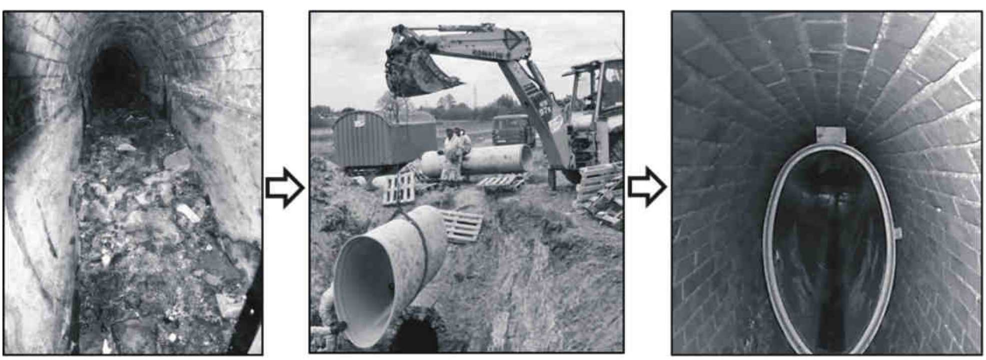

Fig. 4. Sewer rehabilitation using GRP panels: a) sewer before renovation with sludge; b) installation of GRP panel in sewer; c) final result. Photographs: J. Grzanka

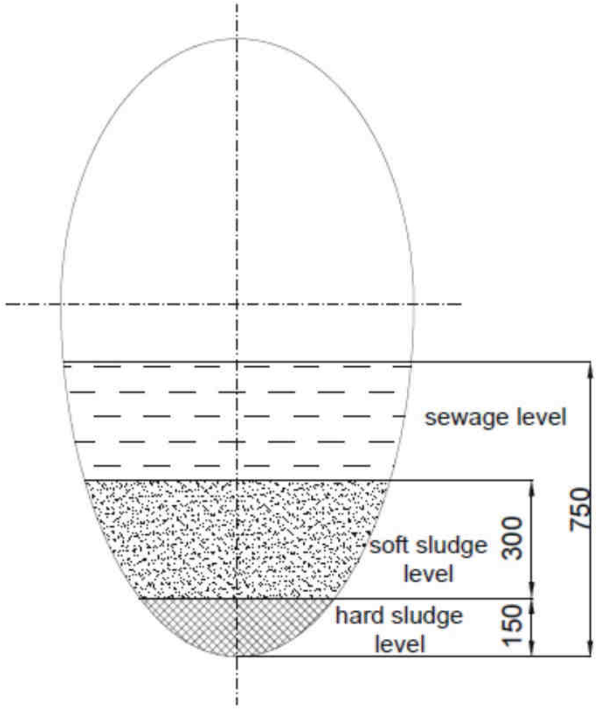

Fig. 5. Levels of sludge and sewage in the investigated sewer. Heights are given in millimetres

The analysis included the occurrence of soft and hard sludge identified during the research (Fig. 5) and significant deterioration of the sewer condition corresponding to a roughness coefficient of 0.03 (according to Manning). For the purpose of calculations, 0.15 m of sludge at the bottom of the sewer was qualified as hard sludge, covered with a 0.30 m layer of soft sludge. While estimating the effective cross-sectional area and wetted perimeter of the sewer pipe, the cross-sectional area of hard sludge was excluded. The roughness coefficient of the sewer after renovation was assumed as equal to 0.009 (equivalent to exceptionally smooth surface) and the fill height as equal to that before renovation, i.e. 0.75 m.

Renovation using cured in place pipe (CIPP) lining

Cured In Place Pipe (CIPP) used as the internal lining of a renovated pipe is made of felt-like fabric saturated with resins, usually polyester or polyethylene resins [27]. The CIPP lining can be used to rehabilitate practically any type of pipe, regardless of its material and shape. For this reason, this technique can be employed when sewer deformations occur, such as crosswise dislocation, cross-section imperfections and variability of the cross-sectional area between consecutive inspection chambers [28]. However, caution is advised when installing a CIPP liner would deteriorate load-bearing qualities of the renovated sewer section, leading to structural failure. Durability of a properly installed CIPP liner is expected to be over 50 years. The liner can be installed regardless of the sewer slope, also in vertical and horizontal position. The CIPP methods can differ, for example, in the way the lining is introduced into the pipe, in the type of curing agent (pressurized steam, hot water, UV radiation) or the length of single lining sections [12].

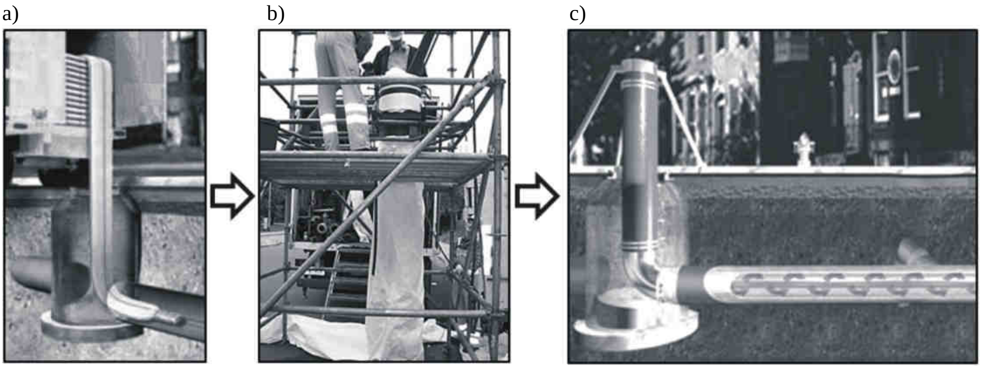

Fig. 6. Sewer rehabilitation conducted using CIPP lining [29]: a), b) installation of CIPP lining in sewer; c) introduction into the pipe hot water - curing agent

The analysis was performed for a cylindrical sewer made of stoneware, having a diameter of 400-500 mm. The aim of renovation was to reduce groundwater infiltration as well as leakages of sewage into the surrounding soil. The sewer was damaged and lost its required water-tightness. The rehabilitation was performed using thermosetting Insituform® CIPP lining over a distance of 670 m. The works are shown in Figure 6. The following assumptions were made for the purpose of calculations: a fill height of 70% of the pipe inner diameter, a roughness coefficient of 0.02 before renovation (sewer in bad technical condition) and 0.01 after renovation (sewer sealed with lining). During renovation, the sewer pipe radius was reduced by the lining thickness, i.e. 12 mm.

Analysis of results

Sewer renovation using GRP panels

The flow velocity in the sewer having been used for 65 years dropped by around 50% in comparison with the sewer built in line with new project goals. In the old sewer, the minimum flow velocity preventing from the accumulation of sludge was not preserved. As a result, layers of hard and soft sludge were deposited at the bottom of the sewer, decreasing its effective cross-sectional area and thereby its flow capacity.

Table 1

Average values of flow velocity and volumetric flow rate in the sewer before and after renovation conducted using GRP panels

	Flow velocity *v* [m/s]	**Volumetric flow rate *Q* [m^3/s]**
Sewer before renovation	0.47	0.21
Sewer after renovation	1.27	0.56

Apart from sealing the sewer and reducing groundwater infiltration, the renovation aimed at restoring its original hydraulic efficiency. Table 1 compares the average values of flow velocity and volumetric flow rate before and after renovation. It was observed that both these quantities more than doubled after the renovation. The resulting velocity was higher than 0.7 m/s; therefore, the sewer is now protected from clogging and can ensure the required flow capacity.

Sewer renovation using Insituform® CIPP lining

The mean flow velocity in the sewer before renovation was equal to around 1 m/s and thereby met the requirements concerning the minimum flow velocity necessary for self-cleaning. Small amounts of sludge were reported. However, renovation was necessary because of groundwater infiltration and leakages caused by aging of the pipe material. As a result of the renovation, the sewer diameter was slightly decreased and its roughness reduced because of the cleaning performed and new lining materials applied. The calculations showed that after the renovation both flow velocity and volumetric flow rate were increased approximately two times and that the new parameters met the self-cleaning velocity requirement. The hydraulic parameters before and after renovation are gathered in Table 2. Thanks to the renovation conducted using a thermosetting liner, the required flow capacity has been preserved along with simultaneous reduction in groundwater infiltration. The new watertight layer can serve for another dozen years without causing trouble in regular operation.

Table 2

Average values of flow velocity and volumetric flow rate in the sewer before and after renovation conducted using CIPP lining (the fill height equals 70% of the sewer diameter)

	Flow velocity v [m/s]	**Volumetric flow rate Q [m^3/s]**
Sewer before renovation	1.05	0.13
Sewer after renovation	2.03	0.23

Summary and conclusions

The sewerage system in Poland is aging and requires renovation. According to the European Council Directive [5], Poland must undertake actions towards rehabilitation of the sewerage network, accompanied by the expansion of wastewater treatment plants. The rehabilitation should strive to seal the network and thus reduce both groundwater infiltration and leakages of sewage into the environment as well as ensure proper hydraulic efficiency of the system. Trenchless rehabilitation methods are most often used in city centres where constricting the traffic can cause serious transportation problems. Moreover, the trenchless methods are less expensive than traditional open cut trench excavation.

There are many trenchless techniques available. A specific technique is selected depending on the sewer location, soil conditions, expected hydraulic capacity and sewer material.

Non-cylindrical large-size sewers can be rehabilitated using GRP panels. The main advantage of this technique consist in the ability to adjust the load-bearing capacity of a sewer and restoring its mechanical durability. In the article, it has been shown that in spite of reducing the cross-sectional area of the sewer during renovation with GRP panels, both flow velocity and volumetric flow rate were approximately doubled in comparison with the state before renovation.

Renovation of sewers using thermosetting resin pipes (CIPP) is advised when the cross-sectional area of a sewer cannot be significantly reduced because of the need to preserve its hydraulic capacity. The CIPP lining can be installed regardless of the sewer pipe material. This type of renovation enhances both flow velocity and flow rate achievable in the sewer.

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