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PROECOLOGICAL TECHNOLOGIES OF SEWERS' REHABILITATION

The aim of the project was to propose the renovation method for damaged sewer and to assess the impact of chosen rehabilitation technology on sewage flow conditions. The bases for the study were technical documentation and channel video inspection. The potential rehabilitation technologies possible to apply in this specific case were presented and the most suitable among them was chosen. By this choice, the environmental aspects were taken into account. The total cost of the bid was calculated. It was indicated that the sewage flow conditions were improved due to channel rehabilitation.

DENOTATIONS

d – internal pipe diameter, m,
h – filling, m,
g – gravitational acceleration, m/s^2,
I – slope of channel bottom,
k – absolute roughness coefficient of the internal pipe wall, m,
ν – kinematic viscosity coefficient of fluid, m^2/s,
V_c – average flow velocity in completely filled duct, m/s,
V_{max} – flow velocity by Q_{max}, m/s,
Q_c – flow capacity in completely filled duct, m^3/s,
Q_{max} – assumed admissible flow capacity in channel, m^3/s,
η_h – filling ratio: $\eta_h = h(Q_{max})/d$,
η_V – flow velocity ratio: $\eta_V = V_{max}(Q_{max})/V_c(Q_c)$,
η_Q – flow capacity ratio: $\eta_Q = Q_{max}/Q_c$.

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1. INTRODUCTION

The main reasons for rehabilitation of sewage channels are bad technical conditions or frequent breakdowns of the sewage pipe system. In some cases, only cleaning of the pipe is needed, but usually the duct has to be repaired, renovated, or reconstructed. The rehabilitation can be carried out traditionally – in the open trench, or by application of trenchless technologies. Repair is optimal when the channel defects are single and slight.

Renovation is preferred when there are serious extended faults along the whole channel section and the channel's dimension can be reduced. It is applied to the whole channel section. The purpose of renovation is to protect the channel walls, seal and/or enforce the construction. Covering inside of the channel with special coating provides isolation of the construction material from an aggressive medium being carried. Alternatively, a special liner is inserted into the host pipe. Its resistance parameters depend on the technology, construction material and admissible thickness of liner walls connected with the reduction of duct diameter [1].

Replacement of the pipe is the most expensive type of rehabilitation method. It is preferred when the old construction is not able to carry any more loads and/or when there is a need for channel cross-section enlargement. The liners applied are highly resistant and able to take over all loads carried by the old pipe so far. For example, in Burstlining technology the old pipe is crushed and displaced into its surroundings by special head. The head is followed by the new pipe placed in the already existing burst [2].

For each specific case of damaged pipe the most suitable rehabilitation method should be chosen and by this selection environmental impact of the methods should be considered. When taking into account the ecological aspect of channel rehabilitation, in most cases the trenchless technologies are favoured. Due to an increasing range of their application and popularity they are often cheaper than conventional open-cut technologies [3].

2. ASPECTS CONSIDERED DURING SELECTION OF REHABILITATION TECHNOLOGY

Channel rehabilitation can be carried out by applying both traditional and trenchless methods. Open-cut technologies have less advantages; however, in some cases, for example, when the damaged channel is located deep in the ground and beyond the street, they are still preferred. In other cases, the modern cheaper and cheaper trenchless technologies are applied. They are much more environmentally friendly than conventional methods due numerous advantages such as [4], [5]:

- protection of vegetation, mainly trees;
- saving of energy, materials and raw materials;
- generation of less emissions such as pollutants, noise and vibrations;

- reduction of waste production.

However, trenchless methods have also some disadvantages:

- rehabilitation difficulties exemplified by disconnection of lateral canals;
- additional costs associated with special quality controls and monitoring procedures;
- high cost connected with recovering the operation in the case of complications [6].

The common mistake made when choosing rehabilitation technique is the selection of the cheapest one without its precise technical assessment and without taking into account its environmental impact. The effect of the rehabilitation should be best and it is usually directly proportional to the operation cost [7]. The choice of rehabilitation technology affects not only the construction costs, but social disturbances involved as well. The parameters influencing the price of the bid include: planning, site investigation and supervision, construction materials, site dewatering, excavation support, transport, waste deposit and site restoration after operation. The calculation is based on marketable prices of materials, work and equipment. In the case of traditional methods, the depth to rehabilitate has a big influence on the cost. The deeper the trench, the more expensive the operation [4].

Social costs are paid by the surrounding community and some time ago they were not taken into account when selecting operation method. Nowadays, due to a deeper awareness among the public and government agencies, care of the environment and society must be taken into account. This transformation was caused by intensification of construction activities and growing traffic congestion in urban areas, as well as widespread environmental awareness. The task is to achieve the best final result, which is directly proportional to construction quality and human satisfaction, but indirectly proportional to the environmental impact, in the shortest time and at the lowest construction and social cost with minimal resource consumption according to the idea of "sustainable development". The negative impact on the society have traffic disturbances, reduction of economic activities, generated emissions and general hazard to social and environmental health. Social costs have the highest value in urban areas. In the case of the costs of traditional methods, they are sometimes even comparable with construction costs, while in the case of trenchless technologies they have usually minimal value.

3. AN EXAMPLE OF ENVIRONMENTALLY FRIENDLY CHANNEL REHABILITATION TECHNOLOGY

3.1. TECHNICAL CONDITION OF THE CHANNEL

The pipe section analyzed in the document is made from stoneware clay pipes of the diameter of 400 mm and a total length of 450.9 m. The channel consists of 18 sections of the length from 17.3 m to 34.6 m. It is located under the street of high traffic intensity, in the vicinity of buildings. The channel is situated in a sandy ground at a depth ranging from 1.43 m (section no. 18 – the start of the channel) to 2.73 m (section no. 1 – the end of the channel). The groundwater table is at a depth of 1.0 m under ground level. Along the channel there are 19 inspection chambers made from concrete rings of 1.2 m diameters.

The channel defects were recognized on the basis of video inspection [3]. The most frequent damages are longitudinal, radiant and circumferential breaks, displacements and local collapses of the pipes as well as leaky joints. Their consequences are groundwater infiltration, salt drips and sand accumulation at the channel bottom. In sections 7, 8 and 9 (table 1), the duct diameter is locally reduced to 295 mm (PCV). There were noticed relatively big slope oscillations of section no. 13. The gentle slope of some sections (no. 1 and no. 7) contributes to accumulation of sediments. Additionally, decreased water consumption observed recently in Polish cities contributes to the reduction of sewage discharge into channel, worsening sewage flow conditions.

Table 1

Flow capacities and flow velocities in completely filled selected channel sections no. 1, 3, 6–9, 13 and the old duct (18)

No. of channel section	No. of manhole		Length of channel section	Diameter of channel d	Slope of channel bottom I	Flow capacity Q_c	Flow velocity $V_c(Q_c)$
	Outlet	Inlet	m	mm	‰	dm^3/s	m/s
1	1	2	24.9	400	**1.20**	**72.1**	**0.57**
3	3	4	34.6	400	3.47	123.2	0.98
6	6	7	17.3	400	9.83	207.9	1.65
7	7	8	26.1	400	2.33	100.8	0.80
			3.9	**295**		**58.9**	0.86
8	8	9	2.1	**295**	5.17	89.7	1.31
			25.9	400		150.6	1.20
9	9	10	2.4	**295**	3.65	74.7	1.09
			25.0	400		126.4	1.01
13	13	14	23.0	400	5.22	151.3	1.20
18	18	19	25.0	400	4.80	145.0	1.15

The purpose of the rehabilitation is to seal the duct, to increase its load capacity and to improve the sewage flow conditions. Due to extensive faults along the channel, the repair would not be effective. The channel should be rehabilitated using some of renovation technologies since the diameter can be reduced.

3.2. SELECTION OF REHABILITATION TECHNOLOGY

The most economical solution would be to apply the same technology to all channel sections. Due to location of the duct and its environmental conditions, the traditional open-cut rehabilitation is excluded. Additionally, if there are laterals connected to the duct, a trenchless operation can be troublesome. In this case, modern rehabilitation technologies are indispensable.

The methods which enable installation using already existing inspection chambers are: Shortlining, Elastic Inserts, Spirally Wound Lining and Deformed Pipe Lining [8]. All these technologies are appropriate for a 400 mm diameter of the channel rehabilitated. Even though there is dimension reduction in sections 7, 8 and 9, the rehabilitation technology will be chosen for the main part of the sewer. For that reason the liner should have the diameter a bit smaller than 400 mm. The parts of the channel of 295 mm diameter can be enlarged by hydraulic expander. The new pipe should follow the leading head and the liner should be installed directly after burst expansion to prevent ground settlement. Additionally, the liner should be rigid like example modules in Shortlining technology. It eliminates Spirally Wound Lining because in this technology the liner is fitted to the host pipe. The time between hydraulic expansion and formation of the final round shape of the new pipe is too long and the risk of ground collapse is too big. It applies also to other methods apart from Shortlining. Elastic Inserts are cost effective only in the case of big projects. Spirally Wound Pipes are not common on the Polish market. Renting and transport of equipment from abroad would be very expensive. Each technology requires specialized training of workers to operate installation equipment. Shortlining is the easiest method to operate and the installation of modules is relatively quick. The construction material is frost-resistant which does not apply to materials used in other technologies mentioned. Aside from all specified advantages, Shortlining is the cheapest technology and it was eventually chosen for rehabilitation of the sewer of interest. There are many modifications of this method available on the market. Among them, the WIR system was selected. In the offer of WIR system company, the Static Burstlining technology is available as well [9]. It can be applied in the case of sections with reduced diameter (no. 7, 8 and 9). It will enable unification of channel material and dimension.

In rehabilitation, the modules of assembling length of 515 mm, internal diameter of 334 mm and external diameter of 355 mm will be applied. The modules are made from very resistant PVC material and their circumferential rigidity amounts to at least 8 kPa. In the WIR system, assembling of modules is done by insertion of a spigot into the socket. The leakproofness of the connection is ensured by two special seals (O-rings) installed in separate grooves. This installation is in the range of the pipe wall and for that reason an internal and external pipe diameter is equal in each place. It is possible to accommodate up to 3° deflection of connections without loss of tightness which makes the modules suitable also for channels with displaced sections of host pipe. The installation is quick, easy and precise (figure 1).

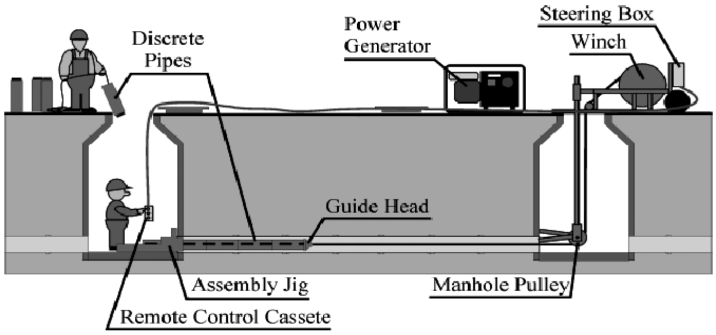

Fig. 1. The scheme of installation of Shortlining WIR system modules [9]

In Static Burstlining WIR System technology, the installation of modules is similar. The leading head is additionally crushing the old pipe and expanding the ground.

Before the operation starts, there is a need for preliminary works, such as channel inspection, cleaning and calibration using test module to ensure the right modules will not be blocked during their installation. The sections no. 7, 8 and 9 to which Static Burstlining will be applied, do not require calibration. During rehabilitation the channel section does not have to be shut down. It is preferred to insert the modules in accordance with sewage flow direction.

4. HYDRAULIC ANALYSIS OF THE OLD AND NEW DUCT

Hydraulic analysis of the old and the new duct will be done to compare the flow conditions and flow capacity in both cases. It was assumed that the duct can work for the most part completely filled. The roughness of channel walls (k) for stoneware clay sewage pipes equals 1.5 mm, and in the case of PCV sewage pipes it equals 0.1 mm. The parameters of sewage flow in completely filled channel of circular cross-section (on the basis of the Darcy–Weissbach and Colebrook–White methodologies [10]) were calculated using the following formulas [3]:

$$V_c = -2\sqrt{2gdI}\,\log\left(\frac{2.51\nu}{d\sqrt{2gdI}} + \frac{k}{3.71d}\right) \Rightarrow Q_c = -\frac{\pi d^2}{2}\sqrt{2gdI}\,\log\left(\frac{2.51\nu}{d\sqrt{2gdI}} + \frac{k}{3.71d}\right),$$

where:

d – an internal diameter of the duct,

g – a gravitational acceleration,

I – the slope of channel bottom,
k – an absolute roughness coefficient of the internal pipe wall,
ν – a kinematic viscosity coefficient of fluid,
V_c – an average flow velocity in completely filled duct,
Q_c – the flow capacity in completely filled duct.

Flow capacity calculations were done for individual channel sections of the old and new duct. In the case of the channel sections no. 7, 8 and 9 of the old duct with different diameters, the calculations were done for each diameter separately. In tables 1 and 2, flow capacities and flow velocities in completely filled selected channel sections of the old and new duct are presented.

Table 2

Flow capacities and flow velocities in completely filled selected channel sections no. 1, 3, 6–9, 13 and the new duct (18)

No. of channel section	No. of manhole		Length of channel section	Diameter of channel d	Slope of channel bottom I	Flow capacity Q_c	Flow velocity $V_c(Q_c)$
	Outlet	Inlet	m	mm	‰	dm^3/s	m/s
1	1	2	24.9	334	1.20	**57.5**	**0.66**
3	3	4	34.6	334	3.47	101.0	1.15
6	6	7	17.3	334	9.83	174.0	1.99
7	7	8	30.0	334	2.33	81.8	0.93
8	8	9	28.0	334	5.17	124.5	1.42
9	9	10	27.4	334	3.65	103.7	1.18
13	13	14	23.0	334	5.22	125.1	1.43
18	18	19	25.0	334	4.80	119.7	1.37

On the basis of information included in table 1 it is found that the minimum flow capacity in the old duct (in completely filled channel sections) is obtained in section no. 7 (58.9 dm^3/s), where the local diameter reduction was noticed. The flow capacity of section no. 1 (bottom location) is small as well and amounts: $Q_{max(old)}$ = 72.1 dm^3/s, which is a consequence of very gentle slope of this section ($I_{(1)}$ = 1.20‰). This value determines the maximum flow capacity of the whole old duct. The free liquid motion in the channel is advisable. However the pressure flow is tolerated in short sections and in the case of maximum flow capacity in the duct it will occur in short part of section 7. Average flow velocity is the lowest in section no. 1 and only in this case this value (0.57 m/s) is much smaller than self-cleaning velocity (0.7–0.8 m/s). This indicates that the slope of this channel section was improperly designed.

On the basis of information included in table 2 it is found that the minimum flow capacity in the new duct (in completely filled channel sections) is obtained in section no. 1 and amounts to $Q_{max(new)}$ = 57.5 dm^3/s. This value determines the maximum capacity of the whole renewed duct. Even though this value is smaller than that before rehabilitation, the sewage flow conditions were significantly improved. In short part of section no. 7, the flow capacity in completely filled duct increased from 58.9 dm^3/s to 81.8 dm^3/s due to its rehabilitation enabling local diameter enlargement. Average flow velocity, e.g., in section no. 1, increased from 0.57 m/s to 0.66 m/s, which is very close to self-cleaning velocity. Similar improvements in sewage flow conditions were observed in other channel sections of renewed duct (tables 1 and 2).

The partial channel fillings $h(Q_{\max})$ and flow velocities $V(Q_{\max})$ for individual channel sections were calculated for assumed maximum flow capacities for the old and new duct (table 3).

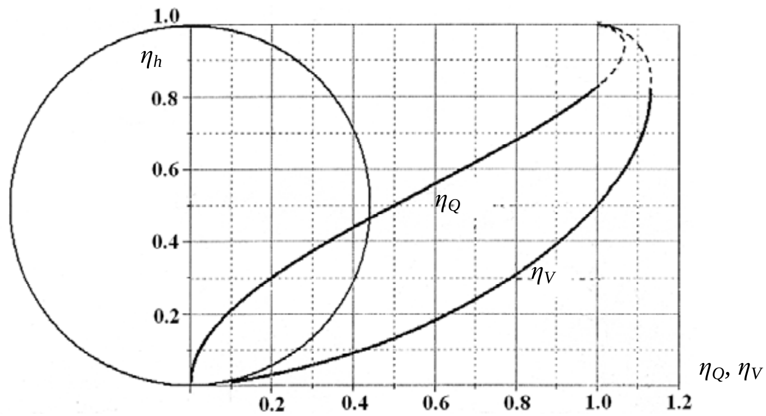

Fig. 2. Efficiency curves for circular channel cross-section

Table 3

Fillings and flow velocities in selected channel sections (no. 1, 3, 6–9, 13 and 18) of the renewed duct at a maximum flow capacity ($Q_{\max(\text{new})}$ = 57.5 dm^3/s)

No. of channel section	Flow capacity Q_c	Flow capacity ratio $\eta_Q = Q_{\max}/Q_c$	Filling ratio $\eta_h = h(Q_{\max})/d$	Filling in the channel section $h(Q_{\max})$	Flow velocity ratio $\eta_V = V(Q_{\max})/V_c(Q_c)$	Flow velocity $V_c(Q_c)$	Flow velocity $V(Q_{\max})$
	dm^3/s	–	–	cm	–	m/s	
1	**57.5**	**1.00**	**1.00**	**33.4**	**1.00**	**0.66**	**0.66**
3	101.0	0.57	0.54	18.0	1.02	1.15	1.17
6	174.0	0.33	0.39	13.0	0.89	1.99	1.77
7	81.8	0.70	0.63	21.0	1.08	0.93	1.00
8	124.5	0.46	0.48	16.0	0.98	1.42	1.39
9	103.7	0.55	0.53	17.7	1.02	1.18	1.20
13	125.1	0.46	0.47	15.7	0.97	1.43	1.39
18	119.7	0.48	0.49	16.4	0.99	1.37	1.36

On the basis of table 3 it was shown that in both cases (except section no. 1) the filling ratios (*h/d*) are close to 0.5, while the flow velocities are higher (16–22% [3]) in the renewed duct. This was indicated based on the efficiency curves for circular channel cross-section (figure 2 [10]).

5. ECONOMIC ANALYSIS OF CHANNEL REHABILITATION

5.1. CONSTRUCTION COST

The cost of channel rehabilitation usually involves construction and social costs. The modules used in both chosen rehabilitation technologies are the same; however, in their price the cost of equipment hire is included. In the case of Burstlining method, this cost is higher. The modules have to be cut in inspection chambers and for that reason the calculation is done for the whole channel section, including length of manholes – 1200 mm. In this way, the reserve of modules is taken into account.

356 running meters (15 sections) of the channel will be renovated using Shortlining WIR System technology, while three sections (85 running meters) will be rehabilitated by applying Burstlining method. Besides the price of modules the cost of PE pipe immobilizing the space between the old and new pipe as well as the cost of cement mortar filling are taken into account. Eventually the cost of materials used for Shortlining rehabilitation is estimated to be: 435.60 PLN/m · 365 m = 159 000 PLN, while the cost of Burstlining materials will be lower (542.20 PLN/m · 85 m = 46 000 PLN) due to smaller length to renew using this technology. The price of rehabilitation of one running meter is higher in the case of Burstlining method. Similarly, the price of work and equipment in this technology is higher due to longer installation and more specialized and more expensive equipment.

The construction cost of rehabilitation in Shortlining amounts to 460.60 PLN/m and in Burstlining method it is equal to 579.70 PLN/m. Total construction cost of rehabilitation is about 218 000 PLN. The average cost of rehabilitation of one meter of the duct is about 484.50 PLN. The social cost was not taken into consideration in this calculation because due to the short installation time and minimal social disturbances during operation this cost will be insignificant [3]. Application of traditional method in the case considered and replacement of the whole duct would be much more expensive (ca. 700 PLN/m · 450 m = 315 000 PLN [4]), when taking into account only the costs of materials, work and equipment. In open-cut technology, the social cost would be additionally drastically increased.

5.2. SOCIAL COST

Social cost of channel rehabilitation with the application of WIR System technology in which the short modules are installed into the host pipe using already existing inspection chambers will be minimal. The avoidance of trenches enables elimination of traffic disturbances and prevents decrease of economic activity of the surrounding community. The emissions and waste generated during operation will be insignificant as well. Bothersome noise connected with the work of generator will last only for a short period of 10 days – which is the planned installation time of modules.

There is always the possibility of failure during operation. Its likelihood is higher in the case of trenched techniques since the liner inserted into the covered duct is difficult to control. However, in the case of the channel of interest, the distances between manholes are not very long (17.3–34.6 m) and therefore the installation is easy to supervise. The responsibility for proper rehabilitation execution is assigned to the workers. All precautions should be taken to avoid the failure.

6. CONCLUSIONS

On the basis of the paper it was concluded that:

1. Desirable rehabilitation effect – sealing of the duct, increasing its load capacity and improving the sewage flow conditions, can be achieved by the application of trenchless WIR System technologies (Shortlining and Burstlining).

2. Hydraulic calculations indicated that after rehabilitation the maximum flow capacity of the duct will decrease by about 20% (from 72.1 dm^3/s to 57.5 dm^3/s), while the cross-section will be reduced by about 30% (from 0.126 m^2 to 0.088 m^2). Simultaneously, the sewage flow velocity will be increased by approximately 20%. This phenomenon is a positive consequence of improved smoothness of the channel walls. A 20% decrease of flow capacity is insignificant in the case considered, since the channel was overdimensioned at designing stage. Nowadays, the channel has big hydraulic capacity reserve and there are rather big problems with accumulation and putrefaction of sediments connected with low sewage flow velocity and high content of suspended matter in the sewage. The rehabilitation will solve these problems.

3. In the article, we have indicated that it is advisable and currently cheap to renew damaged and leaky channels using modern technologies. The rehabilitation will prevent sewage exfiltration into the ground. The diameter reduction of usually overdimensioned ducts and increase of sewage flow velocity will reduce accumulation and putrefaction of sediments. Such operations contribute to protection of the environment.

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PROEKOLOGICZNE TECHNOLOGIE ODNOWY KANAŁÓW ŚCIEKOWYCH

Celem pracy było zaproponowanie sposobu odnowy kanału ściekowego, a także zbadanie wpływu wybranej techniki na warunki przepływu ścieków. Podstawą opracowania była inwentaryzacja stanu technicznego kanału, a także inspekcja video. Zaprezentowano potencjalne, możliwe do zastosowania, techniki odnowy i wybrano najlepiej spełniającą warunki ochrony środowiska. Obliczono całkowity koszt inwestycji. Stwierdzono poprawę warunków przepływu ścieków w odnowionym kanale.