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Development of Technological Solutions for Sewer Rehabilitation Using Clinker Brick

D. F. Goncharenko¹⁾, A. I. Aleinikova¹⁾, S. V. Yesakova¹⁾, R. I. Hudilin¹⁾

¹⁾Kharkiv National University of Civil Engineering and Architecture (Kharkiv, Ukraine)

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Abstract. The aim of the work is to develop a technology for the restoration of damaged sections of sewer collectors using clinker bricks. A significant part of such collectors in the Ukraine has completely exhausted their depreciation resource. For their construction, concrete and reinforced concrete were used, which are subject to destruction as a result of the influence of many factors and, above all, microbiological corrosion. Therefore, the selection of the optimal repair technology using corrosion-resistant clinker brick is relevant. The paper considers the problems of repair and reconstruction of worn-out collectors. Technical and technological solutions of an open method for their recovery using pneumatic formwork and corrosion-resistant clinker brick are presented. The design of the collector lining structure has been carried out using the finite element method. To justify the feasibility of using the proposed technology, two options for restoring a worn-out collector have been considered: the “pipe-in-pipe” method and method developed by the authors using clinker bricks. The second option in terms of the cost of materials is almost four times more economical and more expedient than the first one (where polymer materials are used). The advantage of restoring circular sewer collectors by means of laying clinker bricks lies in the durability and resistance of this material (taking into account the anticorrosive composition of concrete) to the aggressive effects of the sewer environment. It should be noted that the application of the developed restoration technology is the most appropriate in conditions of sparse building or outside the city due to the significant volume of earthworks.

Keywords: sewer, wear, biogenic corrosion, emergency damage, restoration technology, brick, pneumatic formwork, finite elements method

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Разработка технологических решений восстановления канализационного коллектора с использованием клинкерного кирпича

Докт. техн. наук, проф. Д. Ф. Гончаренко¹⁾,
кандидаты техн. наук А. И. Алейникова¹⁾, С. В. Есакова¹⁾,
асп. Р. И. Гудилин¹⁾

¹⁾Харьковский национальный университет строительства и архитектуры (Харьков, Украина)

Реферат. Разработана технология восстановления с применением клинкерного кирпича поврежденных участков канализационных коллекторов. Значительная часть таких коллекторов в Украине полностью исчерпала свой амортизационный ресурс. Для их строительства использовались бетон и железобетон, которые подвержены разрушению при воздействии многих факторов и прежде всего микробиологической коррозии. Поэтому выбор оптимальной технологии ремонта с применением коррозионно-стойкого клинкерного кирпича является актуальным. Рассмотрены проблемы ремонта и реконструкции изношенных коллекторов. Приведены технические и технологические решения

Адрес для переписки

Алейникова Алевтина Игоревна
Харьковский национальный университет
строительства и архитектуры
ул. Сумская, 40,
61002, г. Харьков, Украина
Тел.: +380 66 291-31-87
alevtynaal222@gmail.com

Address for correspondence

Aleinikova Alevtyna I.
Kharkiv National University
of Civil Engineering and Architecture
40, Sumskaya str.,
61002, Kharkiv, Ukraine
Tel.: +380 66 291-31-87
alevtynaal222@gmail.com

открытого способа их восстановления с использованием пневматической опалубки и коррозионно-стойкого клинкерного кирпича. Расчет конструкции обделки коллектора выполнен с помощью метода конечных элементов. Показаны преимущества и недостатки предложенных решений, приведены примеры их практического применения. Для обоснования целесообразности использования данной технологии рассмотрены два варианта восстановления изношенного коллектора: методом «труба в трубе» и разработанным авторами методом с применением клинкерного кирпича. Второй вариант по стоимости материалов практически в четыре раза экономичнее и целесообразнее первого (где используются полимерные материалы). Преимущество восстановления канализационных коллекторов круглого сечения путем устройства кладки из клинкерного кирпича заключается в долговечности и устойчивости этого материала (с учетом антикоррозионного состава бетона) к агрессивному воздействию канализационной среды. Следует отметить, что применение разработанной технологии восстановления наиболее целесообразно в условиях неплотной застройки или за пределами города ввиду значительного объема земляных работ.

Ключевые слова: канализационный коллектор, износ, биогенная коррозия, аварийное повреждение, технология восстановления, кирпич, пневматическая опалубка, метод конечных элементов

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Introduction

The distribution system of sewerage utility systems is a sophisticated complex of facilities for sustainable sewage disposal. Its key elements include drainage pipelines and sewage tunnel collectors of various diameters characterizing the degree of development and redevelopment of a city. Under current conditions Ukrainian operating enterprises carry out their activities on the brink of their technological and organizational capabilities, as evidenced by high depreciation of fixed assets and emergency condition of many networks due to insufficient financing of the industry [1]. As of 2015, the total length of drainage networks in Ukraine was 37.404 thousand km, including drainage networks in an emergency condition: 12.749 thousand km or 34 %. Compared with 2014, the total length of emergency drainage networks increased by 459 km or 3.6 % for the whole country. Share of emergency drainage networks in Kharkiv in their whole length is 42 %. The trend of recent years indicates that the length of emergency networks increases annually by 0.67 % [2].

It is known that most of the sewers with a diameter of 700 to 1800 mm were built of concrete and reinforced concrete 40–50 years ago. As evidenced by the analysis of the occurrence of emergency situations in the water disposal networks in Ukrainian cities, frequently, concrete and reinforced concrete structures of sewers fail long before their rated service life [1, 2]. The study of the operation life of sewers shows that up to 80–90 % of accidents in reinforced concrete pipelines are due

to corrosion processes. Chemical reactions occurring in the free space of the pipeline form an aggressive environment for concrete structures. The arch structures of the sewer are most susceptible to biogenic corrosion [3]. Accidents and failures in the operation of sewer networks lead to obvious economic, environmental and societal effects.

Research of Ukrainian and foreign scientists in the field of operational resources suggests [4–13] the sewer fall into decay due to the following reasons: penetration of surface water inside the structures; static and dynamic loads generated by truck transport; deviations from the codes and errors in construction; poor quality of the shaft wall surface; aggressive biological environment; ground subsidence. The questions of studying the physicochemical properties of concrete are devoted to work, as well as to the processes of hardening of concrete in an environment, articles by scientists are devoted [14–16]. Currently, the relative share of emergency water disposal networks in Kharkiv is 42 % of their total length. The trend of recent years shows that the length of emergency networks increases annually by an average of 0.67 % per year [17], and emergency situations are increasingly common. At the beginning of 2018, a collapse occurred at seven sites of the Southern gravity sewer in the town of Lozovaya in Kharkiv region. The analysis of the accident pointed out a number of reasons for the sewer to be taken out of serviceable condition, as follows:

– a decrease in the amount of drains by a factor of 2 to 3 over the past 20 years;

- an increase in aggressivity of waste water (exceeding the maximum permissible concentration of ammonium nitrogen by 1.5 times, of phosphates by more than 4 times);

- a reduction in the flow velocity;
- an increase in the amount of precipitation.

Over the course of its operation (over 30 years), the reinforced concrete arch has been almost completely deteriorated as a result of the action of biogenic corrosion [18, 19]. Moreover, significant collapses occurred on the sewer that conveys waste water from the area where the Kharkiv Tractor Plant is located to the treatment facilities (Fig. 1).

Given the sewers are laid at a shallow depth and there are no buildings or related structures, no motorways or pedestrian walkways or other utility facilities being located in the area of sewer deterioration, repair and rehabilitation work by open cut is proven to be expedient. The open-cut method of repair and rehabilitation allows for:

- increasing or decreasing the cross-section of the conduit, depending on the design needs;
- additionally making connections from various facilities, and connecting manholes built on the site under repair;
- carrying out repair and rehabilitation work irrespectively of the cross-section of the conduit section to be rehabilitated, the length of the run, the base of the conduit, the materials used;
- carrying out work irrespectively of the geological and hydrogeological conditions and the depth of the sewer conduit.

Sewer rehabilitation using the conventional open-cut method involves excavating a trench [20], dismantling a worn-out sewer, and installing a new sewer made of materials that can resist biogenic corrosion, such as pipes made of polyethylene, fiberglass and others (Fig. 2).



Fig. 1. Sewer deterioration in the area of the Kharkiv Tractor Plant due to biogenic corrosion



Fig. 2. Repair of pipelines using a traditional pipe method

The use of polymeric materials for sewer repair is common. The polymers have high resistance to biogenic corrosion. At the same time, polyethylene and fiberglass are expensive materials. In conditions of limited funding for the sewerage industry, the issue of cost savings is a priority.

An analysis of the first sewers in European cities shows that most of the sewers were built of clinker brick. Brick sewers of circular cross-section with a diameter of 700 to 1800 mm, with a standard or enlarged saddle, and of semi-elliptic (hipped) cross-section for large sizes, are more consistent with the static working conditions, and where high-grade brick is used, durable and resistant to aggressive ground and waste water [21]. In Ukrainian cities, clinker brick also found its use in the construction of sewage systems in Kyiv in 1893 (Fig. 3) and in Kharkiv in 1914 (Fig. 4) [22]. However, the need to erect structures that are complex in terms of capacity and geometry for the arch of the sewer to be built has resulted in replacing brick sewers with precast reinforced concrete conduits.



Fig. 3. Sewers built of clinker brick in Kyiv



Fig. 4. Sewers built of clinker brick in Kharkiv

The introduction in recent years of mobile pneumatic formworks, which are capable to replace complex structures for the arched section of the sewer to be built, enables repair and rehabilitation of sewers using clinker brick. The purpose of this work is to develop a technology for rehabilitating damaged sections of sewers using clinker brick:

- to achieve the study's objectives, the following tasks were set;
- to perform an analysis of the occurrence of emergency situations in sewers with a diameter of 700 to 1800 mm;

- to review the existing technologies of rehabilitation of water disposal networks;
- to develop a sewer rehabilitation technology using clinker brick to extend their operation life.

Sample site and instruments

In order to determine the properties of the main elements (ceramic brick and mortar) of the arch section of the sewer, which was built in 1931 in Kharkiv, the samples that had been used in aggressive environments over 85 years were submitted to the laboratory of construction materials and products of Kharkiv National University of Civil Engineering and Architecture [22]. After they were tested, it was found that the brick of which the sewer was built was in normal condition and was slightly deteriorated by corrosion; biogenic corrosion of the seams caused mechanical damage to the brickwork [22]. Hence, clinker brick are capable to resist biogenic corrosion, which makes it a suitable material for rehabilitating and repairing water disposal conduits, provided that a properly designed concrete mixture is used for mortar, which is able to resist corrosion.

Given the fact that, generally, the arches of the reinforced concrete sewers in operation are destroyed due to the effect of corrosion, while the invert is in satisfactory condition, the authors have developed a sewer rehabilitation technology using clinker brick by open cut (Fig. 5).

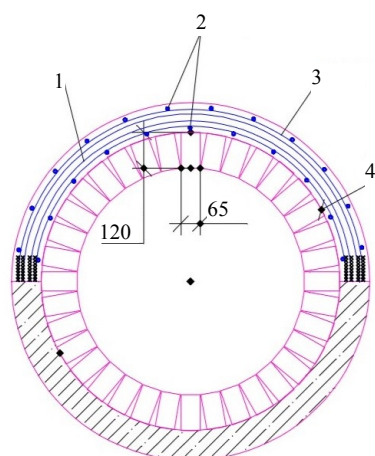


Fig. 5. Schematic diagram for arrangement and reinforcement of the sewer of clinker brick with a protective arch of cast-in-situ concrete: 1 – invert section of the sewer to be rehabilitated; 2 – brickwork; 3 – arch reinforcement 4 – protective arch of cast-in-situ concrete

The arch is built by brick laying using clinker brick in several stages:

- 1) arranging waste water disposal;
- 2) excavating a trench;
- 3) dismantling the damaged sections of the sewer (arch, walls);
- 4) clearing the invert section of the sewer;
- 5) brick laying of the invert section of the sewer (in case of deterioration of the invert);
- 6) cleaning the existing reinforcement to ensure the combined behavior of the invert and the erected protective lining of the arch;
- 7) arranging the pneumatic formwork for the brick laying of the arch using clinker brick;
- 8) brick laying of the arch of the sewer;
- 9) arranging the required reinforcement for the protective lining of the arch of cast in-situ reinforced concrete;
- 10) laying of concrete mix of the cast-in-place section of the arch;
- 11) removing the pneumatic formwork after concrete strength is achieved;
- 12) backfilling the trench.

To assess the bearing capacity and the combined behavior of the proposed structure of the arch, its stress state has been calculated under the following conditions: the diameter of the existing sewer is $D = 1500$ mm, the height of backfill soil over the arch of the sewer is $H = 3$ m, the specific gravity of soil is $\gamma = 20$ kN/m³, the design resistance is $R = 20$ t/m². The calculation has been performed by the finite element method using SCAD software; the model is shown in Fig. 6. The data on the reinforcement power for the cast-in-situ reinforced concrete arch are given in Fig. 7, 8.

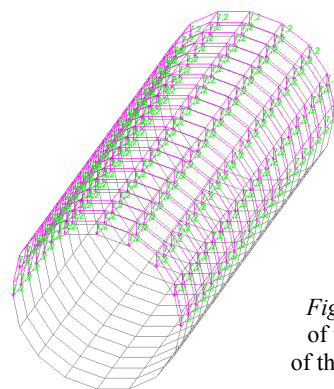


Fig. 6. The design model of the proposed structure of the cast-in-situ reinforced concrete arch

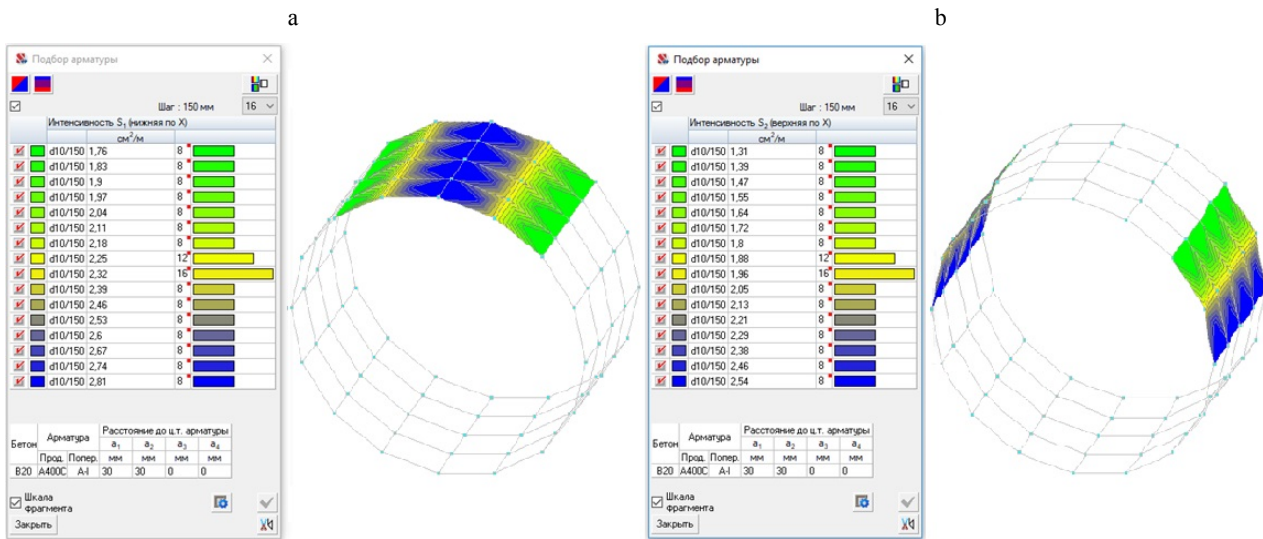


Fig. 7. The reinforcement power of the reinforcement at a pitch of 150 mm in x direction: a – lower; b – upper

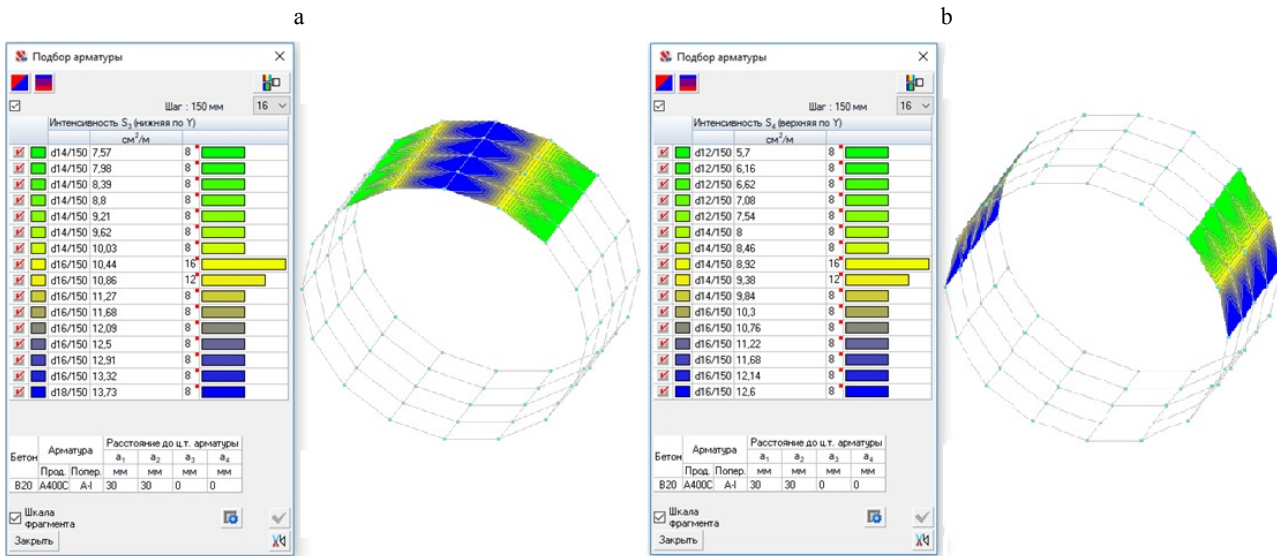


Fig. 8. The reinforcement power of the reinforcement at a pitch of 150 mm in y direction: a – lower; b – upper

Results

The cladding process cycle included a series of four main operations such as installation of anchors and holding channels; installation of reinforced slag cast panels; filling the space behind the sections with concrete mixture; coating the plate joints with modified epoxy resin or polyurethane. The specifications of the cast-in-situ structure elements for the rehabilitation of 1 (one) running meter of the sewer are listed in Tab. 1. Clinker brick and mortar are not taken into consideration in this case due to the need for clarification regarding

the type of brickwork for each individual case and the repair section of the sewer.

Table 1
Specifications of the cast-in-situ structure elements for the rehabilitation of 1 (one) running meter of the sewer

Item No	Description	Number, pcs.	Mass of a unit, kg
1	Reinforcement Ø18A400C, L = 1690, DSTU 3760:2006	6	3.380
2	Reinforcement Ø10A400C, L = 1000, DSTU 3760:2006	23	0.617
3	Reinforcement Ø16A400C, L = 1820, DSTU 3760:2006	6	2.870
4	Concrete, class C16/20, W4, F100	0.18	

To substantiate the expediency of using the proposed technology, two options for rehabilitating a worn-out sewer have been considered: the “pipe-in-pipe” method and the method developed by the authors involving clinker brick. The comparison of the performance indicators is shown in Tab. 2.

Table 2

Cost of technological solutions for rehabilitating a Ø1000 mm conduit, section length: 100 running meters

Item No	Description	Labor intensity, man-hours	Total cost of material, c.u.
1	Sewer rehabilitation by open cut using the proposed method involving clinker brick	740	5000
2	Sewer rehabilitation by open cut by laying SPIRO SN 6–8 corrugated polyethylene pipe	834	21000

From Tab. 2 it follows that sewer rehabilitation involving clinker brick is almost four times more cost effective and expedient in terms of the cost of materials than that involving SPIRO PE pipes. The advantage of the rehabilitation of sewers of circular cross-section by laying clinker brick resides in the durability and resistance of this material to aggressive effects, with due consideration of corrosion-resistant concrete composition. It should be noted that the use of the developed rehabilitation technology is most appropriate in the conditions of small built-up areas or outside the city limits due to a significant amount of earth works.

CONCLUSIONS

1. The experience gained over recent years in repair and refurbishment of sewers clearly shows high efficiency of the technologies applied in this case using structures made of various protective materials.

2. Sewerage networks are among the most critical elements of the centralized water disposal system, so the selection of the optimum repair and refurbishment technology is an urgent task. The technologies of rehabilitation collector using traditional materials, polymers, clinker bricks and protective coatings proved to be highly effective. The above reconstruction and refurbishment technologies have a number of benefits as follows. The use of polyethylene and fiberglass pipes in-

creases the service life of sewage systems by up to 50 years or more, since polyethylene and fiberglass have a high chemical resistance when used in aggressive environments.

3. The cost of polymer pipes is quite high. As studies show, sewer networks made of clinker bricks have been in operation for more than 100 years. Moreover, the reliability of these networks is not compromised. The developed technology of sewer repair using clinker bricks allows to save financial resources. The calculations of the carrying capacity of the construction with clinker bricks show the possibility of using this technology for the repair of sewers.

4. The technology of rehabilitation sewage collector with the clinker brick will find its application in unpopulated areas, since it is inappropriate to use it in cramped buildings.

5. In conditions of limited financial resources and high cost of imported polymer pipes for Ukraine, the technology proposed by the authors deserves special attention. The final version of the sewage repair technology can be selected according to the specific conditions of the construction operations and technical and economic indicators of the considered cladding choice.

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