Restoration of dilapidated pipeline networks using polymer hoses

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Abstract. The paper considers a set of issues affecting the actual problems of operational repair and restoration work on underground pressure water and drainage pipelines made of various materials that have exhausted their standard service life and are subject to numerous defects in the form of cracks, joint divergences, rust growths, fistulas and others. The aim of the work is to consider trenchless technology as a promising method of repairing dilapidated pipelines, which uses the application of polymer hoses to the inner surface of pipeline networks. The general requirements for flexible polymer sleeves and their characteristics, the scope of application of sleeves, as well as requirements for structural materials used in the production of flexible polymer sleeves are considered as the subject of research. The result of the work is an analysis of the sequence and essence of preparatory operations, including in-line diagnostics and a coding system for the results of visual inspection of pipelines. As conclusions, examples of calculating energy savings during water transportation before and after repair and restoration work at an exemplary facility are given, depending on the technical characteristics of the hoses used, as well as their thickness, depending on the depth of the pipeline.

Keywords: underground pipeline, in-line diagnostics, defects, coding system, polymer hoses

Introduction

The reliability of engineering networks plays an important role in modern urban economy, ensuring an unhindered supply of drinking water to consumers and the discharge of wastewater to treatment facilities, creating appropriate sanitary and hygienic conditions for normal human life and ensuring the environmental safety of underground space and the atmosphere of cities [1-3].

Currently, about 50% of Moscow's pipeline communications have almost exhausted their standard service life. In accordance with the Decree of the Government of Moscow "On approval of water supply and sanitation schemes of the city of Moscow for the period

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up to 2025", the development of communal systems for the next 10 years is determined, where the total planned costs for the modernization of water management systems is 352,563.8 million rubles.

Long-term trouble-free, safe and efficient operation of pipelines for the transport of liquids is a complex task, which requires a systematic approach to the design, construction (laying) of the pipeline, its operation (damage analysis, quality of service), as well as the development of the necessary regulatory framework [4]. At the same time, we are talking about both new construction and the possible re-laying of existing pipelines using pipe products made of modern structural materials. The agenda also includes issues of preventing emergencies when the groundwater level decreases and deformations of underground utilities in the zone of influence of pipelines under construction [5, 6].

A relatively affordable, prompt and effective method of restoring the operation of failing pipelines is their repair using trenchless technologies [7-9]. Trenchless pipeline reconstruction methods are diverse and include the use of sprayed protective materials, dragging new pipes of smaller diameter into old pipelines, using winding technology and others. Recently, a special place has been given to multilayer polymer hoses, which, after being dragged inside the old pipeline, undergo polymerization, forming an independent supporting structure inside the old pipeline. Two methods are used as methods of sleeve stretching: "eversion" and "inflating" sleeves [10, 11].

If we are talking about pressure pipelines, then the goal is to restore not only the strength characteristics of the old pipeline, but also to help reduce energy consumption during the transportation of liquids. This allows the operation of networks to meet the conditions of their long-term operation and optimal power consumption by reducing the roughness of the pipe walls [12-15].

Thus, the application of the trenchless pipeline reconstruction method by using polymer hoses with a smooth inner surface, as well as the implementation of the method in practice to increase the reliability of engineering networks and achieve an energy saving effect is one of the urgent tasks of designers, builders and urban management services.

Materials and methods

The research materials are dilapidated underground pressure pipelines that are being diagnosed for the detection and fixation of defects. The methods are analytical analysis and computational and theoretical justification of the use of polymer hoses to achieve the effect of resource and energy saving during water transportation. During the analytical stage, the requirements for polymer hoses as building materials and the results of in-line diagnostics, including coding of detected pipeline defects, were considered. The computational and theoretical stage consists in comparing the results of the values of electricity consumption during water transportation based on the choice of the sleeve thickness with its corresponding strength characteristics and the depth of the pipeline.

A dilapidated cast-iron pipeline with an internal diameter of 0.4 m and a length of 400 m, lying at a depth of 3.0 m, is considered as an object of restoration. Based on preliminary calculations for two alternatives, the following values were obtained: for the elastic modulus of the sleeve E (3500 N/mm^2) based on fiberglass and its bending strength δ (75 N/mm^2) to ensure the bearing capacity of the pipeline, the wall thickness of the sleeve should be 5.1 mm, and the inner diameter of the restored pipeline $0.4 - 2 \cdot 0.0051 = 0.3898$ m; with the elastic modulus of the sleeve E (1400 N/mm^2) based on polymer fibers and its bending strength δ (18 N/mm^2), the wall thickness of the sleeve should be 7.3 mm, and the inner diameter of the restored pipeline $0.4 - 2 \cdot 0.0073 = 0.3854$ m [16].

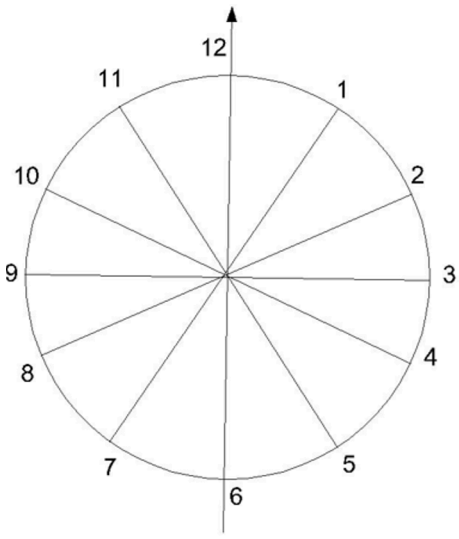
Research results and their discussion

The analytical stage.

Underground pressure pipelines, regardless of the materials of manufacture, are subject to various types of damage during long-term operation. One of the effective methods of restoring their operability is the use of polymer protective coatings in the form of flexible hoses applied to the inner surface of the pipeline and cured using water pressure, steam, as well as exposure to ultraviolet radiation.

Before applying a trenchless pipeline repair technology, its visual inspection is carried out using modern telediagnostic complexes, including coding defects both along the length of the repair section of the pipeline and at a specific location on its inner surface, i.e. by positions on the pipe axis and on the circumference. Thus, each damage to the pipeline network must be described using a digital code. In particular, the position of a particular damage located in the arch (shelyge) of the pipeline is recorded by the number 12. The damage boundaries are indicated in time coordinates. If a single value is required, the value of the dial scale in the middle of the object is indicated, and if damage is detected at different points of the circle, they are encoded separately.

Figure 1 shows the values of the angles corresponding to a certain time value on the dial, and Figure 2 shows examples of determining the boundaries of detected damage on a circle, where a bold line shows the area of the defect on the inner surface of the pipeline.



Angle, degree	Hours
0 ± 15	12
30 ± 15	01
60 ± 15	02
90 ± 15	03
120 ± 15	04
150 ±15	05
180 ± 15	06
210 ± 15	07
240 ± 15	08
270 ± 15	09
300 ± 15	10
330 ± 15	11
360 ± 15	12

Fig. 1. The values of the angles corresponding to a certain time value on the dial

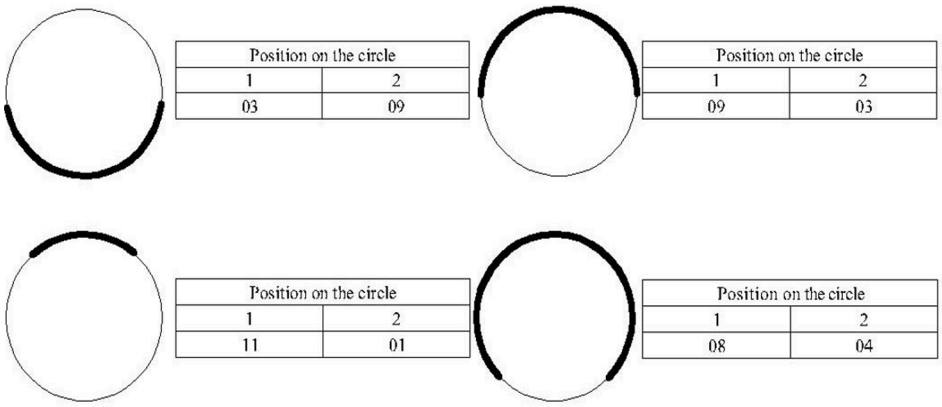


Fig. 2. Examples of determining the boundaries of detected damage on a circle

The position of each damage is recorded by indicating the distance from the reference point along the horizontal axis. The reference point can be: the inner wall of the initial node (well, inspection hole, etc.). Coordinates are specified in meters with an accuracy of one tenth. When photographing an object, it is necessary to ensure that the camera location can be determined. If the examination is recorded on video, then the position of the damage must be unambiguously recorded. The time code is given in the format *hh*: *mm*: *ss*. Encoding of the results of the visual examination is necessary for further computer processing and data transmission to the geoinformation system. Based on the results of the survey, an act, conclusion or report on the technical condition of the pipeline structure is drawn up and the need for a list of repair and restoration measures for the near and subsequent future is justified. In the case of choosing the primary renovation object, the most optimal repair method is determined for it [17-20].

When choosing polymer hoses as one of the effective potential repair materials used in trenchless pipeline renovation technologies, the requirements for them should be taken into account and the technical characteristics of the structural materials that form the basis for the production of hoses should be studied. The basic design element of the flexible polymer sleeve is: a base (made of polymer fibers or fiberglass) and a system of reaction resins (for example, *EP* epoxy resin; *UP* unsaturated polyester resin; *VE* vinyl ester resin).

The restoration of damaged networks using flexible polymer hoses, in which reaction resin systems are used as a binder, involves the installation of a new pipe made of composite material inside the existing pipeline. During the curing of reaction resins, the flexible polymer sleeve is transformed into a strong, elastic, seamless pipe that fits snugly to the inner surface of the old pipeline.

Flexible polymer hoses are used to restore pipelines with nominal diameters of 50-2600 *mm* from any structural materials with different cross-sectional shapes. The wall thickness of the new composite pipe is calculated taking into account the existing static loads and must be at least 4 *mm*. The use of flexible polymer hoses is possible to eliminate the following defects: the presence of inlays / deposits (after their removal); longitudinal displacement of pipes (if the axial displacement of pipes is no more than 3 *cm*); mechanical abrasion and corrosion of concrete (after preliminary work on sealing areas with exposed reinforcement); pipe displacement (in the absence of voids in the area joints of individual pipe modules); single cracks and cracks over large areas (with preliminary consideration of extreme deformations); germination of tree roots (with their preliminary removal); absence

of a part of the pipe (possible with the edge length of the missing part of the pipe being less than half the diameter of the pipeline).

The choice of materials for a flexible polymer sleeve is determined by its design and production technology, as well as requirements for strength, hydraulic, functional characteristics and environmental safety of the new pipe formed inside the pipeline being restored. To restore a specific section of the pipeline from the appropriate material, it is necessary to have information about the technical parameters of the sleeve (for example, the modulus of elasticity and bending strength), its environmental safety and compatibility with technological equipment. The technical characteristics of the sleeve must be confirmed by the results of tests performed by an accredited organization.

Before installing a flexible polymer sleeve using its inversion operations, the following measures are carried out:

-organization of drainage using needle filters (if there is an underground water horizon above the repair section of the pipeline);

-closing of the repair interval and two adjacent sections with valves;

-dismantling of two valves at the edges of the repair interval;

-cleaning of the restored interval, for example, with high-pressure water, using special nozzles or hydromechanical cleaning;

-visual inspection of the site condition by television cameras;

-registration of defect locations.

As an example illustrating the application of a polymer sleeve to the inner surface of the pipeline, Figure 3 is shown, where the sleeve is installed using an inversion drum.

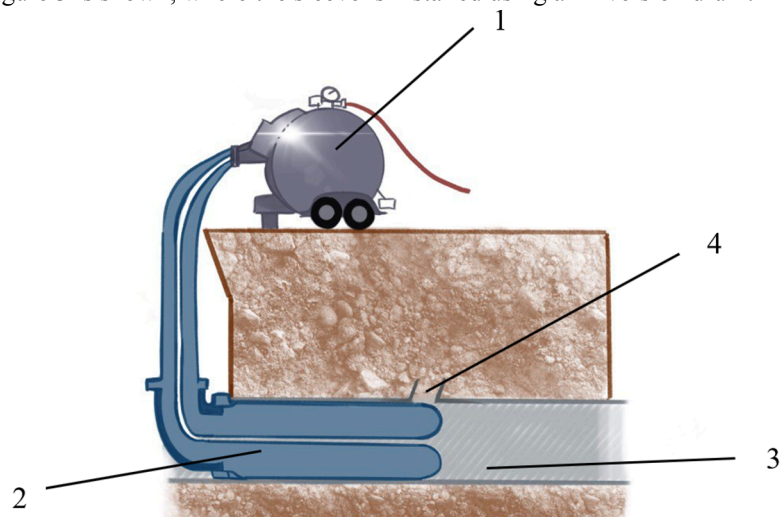


Fig. 3. Inversion of a flexible polymer sleeve using a special drum
1- inversion drum; 2- polymer sleeve; 3- repair site; 4- pipeline defect

In this case, compressed air is used to invert the sleeve and press it tightly against the inner wall of the pipeline. At the same time, the pressure that presses the sleeve against the inner surface of the pipeline during the entire curing process must remain constant and ensure the necessary shape of the new pipe. When installing the sleeve, it should be protected from mechanical damage. For this purpose, when retracting the sleeve into the pipeline to be restored, it is necessary to move it deeper into the pipeline with a constant force, the value of which does not exceed the maximum permissible value set by the sleeve manufacturer, as well as to ensure measurements and registration of the values of the

retracting forces. After installing the hose in the old water pipeline and polymerizing it, telediagnostics, hydraulic tests and disinfection are carried out at the repair site. Disinfection is not performed during repair work on pressure drainage networks.

In case of successful pipeline repair operations recorded by telediagnostics, i.e. the absence of longitudinal, transverse folds and ruptures, the facility is put into operation according to the protocol drawn up by the contractor and the customer. In extreme cases, when these defects are found in any place, taking into account their nature and size, the restored section is subject to repeated repair along its entire length, for example, using the technology of dragging a polymer pipeline into it. It is also possible to tear off the trench and replace a part of the pipeline with defects with a pipe material identical to the old pipeline.

The settlement stage.

The purpose of the calculation was to determine the energy savings in the pressure pipeline, restored using the technology of applying a polymer sleeve using the inversion method by reducing the hydraulic resistance along the length of the repair section of the pipeline.

The initial data for the calculation are presented above in the section of this article "Materials and methods".

The calculation of energy consumption savings for two alternative repair options is performed according to formulas (1) and (2) [14].

$$\Delta E_{1m}=[9{,}81\cdot Q^3(A_s - A_n)\cdot 24\cdot 365]/\eta_p \quad (1)$$

where ΔE_{1m} is the amount of savings in electricity consumed, *kWh*/year; Q is the consumption of transported water, m^3/s; A_s and A_p are, respectively, the resistivity coefficients of the old and new pipelines, i.e. with a polymer sleeve; η_p is the efficiency of the pumping unit; 24 is the number of hours of pump operation per day, *h*; 365 –the number of days in a year

$$A_s = 0{,}0017 d_s^{-5{,}1359}, \quad A_n = 0{,}0007 d_n^{-5{,}2791} \quad (2)$$

where d_s is the inner diameter of the old pipeline, *m*; d_n is the inner diameter of the new pipeline, *m*

We accept the flow rate of transported water Q = 0.134 m^3/s, the efficiency of the pumping unit η_p =0.85, the inner diameter of the old pipeline d_s = 0.4 *m* and the diameters after reconstruction d_{n1} =0.3898 *m* (when using a sleeve based on fiberglass) and d_{n2}=0.3854 m (when using a sleeve based on polymer fibers).

For the option of reconstruction of the old pipeline using a polymer sleeve based on fiberglass, the value of ΔE_{1m1} (*kWh* per year per 1 *m* of pipeline length) will be:

$$\Delta E_{1m1}= [9{,}81\cdot 0{,}134^3(0{,}0017\cdot 0{,}4^{-5{,}1359}- 0{,}0007\cdot 0{,}3898^{-5{,}2791})\cdot 24\cdot 365] / 0{,}85=21{,}112$$

For the option of reconstruction of the old pipeline using a polymer sleeve based on polymer fibers, the value of ΔE_{1m2} (*kWh* per year per 1 *m* of pipeline length) will be:

$$\Delta E_{1m2}= [9{,}81\cdot 0{,}134^3(0{,}0017\cdot 0{,}4^{-5{,}1359}- 0{,}0007\cdot 0{,}3854^{-5{,}2791})\cdot 24\cdot 365] / 0{,}85=19{,}603$$

Comparing the calculated data, it can be noted that the most profitable option in terms of saving electricity when transporting water after renovation operations of the old pipeline is using a polymer sleeve based on fiberglass, where the difference in values of ΔE_{1m1} and ΔE_{1m2} is 21.112-19.603 =1.509 *kWh* per year.

Thus, the total annual energy savings of ΔE (*kWh* per year) due to the reduction of hydraulic resistance along the entire length of the dilapidated repair site after its renovation operations with a polymer sleeve based on fiberglass will be:

$$\Delta E=\Delta E_{1m1}\cdot l=21{,}112\cdot 400=8444{,}8$$

where *l* is the length of the pipeline to be renovated (400 *m*)

Conclusions

1. The main stages of the process of reconstruction of dilapidated engineering networks by using trenchless technology of applying a flexible polymer sleeve to the inner surface of the pipeline are presented.

2. The principle of fixing damages on a dilapidated pipeline using a digital code to determine the boundaries of the identified defects on the circumference is described.

3. A method for calculating energy savings during water transportation in a pressure pipeline after its repair is presented using two types of polymer hoses with an appropriate wall thickness depending on the depth of the pipeline, the bending strength of the sleeve and the modulus of elasticity.

4. According to the calculations carried out, for the specified design parameters, an energy saving effect can be achieved when transporting water through a pipeline from the use of a polymer sleeve as a repair material, which is 8444.8 *kWh* per year in digital terms.

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