Approaches to the automated design of restoration work on dilapidated gravity pipeline networks in the presence of foul-smelling gases in them

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Abstract. The article considers the problems of improving the efficiency of design, construction, and reconstruction of gravity-flow pipeline networks based on computer modeling, as well as automation of estimated calculations, considering the use of modern trenchless technologies. The authors present the solution to a problem of a choice of the optimum variant of repair from among alternatives at the reconstruction of a dilapidated pipeline from chrysotile cement of the corresponding diameter and extent in which underlying space there is a foul-smelling and aggressive gas (hydrogen sulfide) in the quantity considerably exceeding its maximum permissible concentration in the atmosphere of cities. Computer modeling considered maximum permissible concentrations of harmful gas emissions and values according to data from organizations operating the network. The results of the work of the automated complex are temporal characteristics of removal of gas components at the organization of artificial air exchange in the under-flowing space of the gravity pipeline at the expense of the selection of productivity of ventilation units. We estimated the cost parameters of preparatory, basic, and finishing construction-technological operations in the complex of works on estimating repair-construction works. For example, mechanical cleaning of the inner surface of the drainage pipeline, organization of dewatering in case of groundwater level above the pipeline, and television inspection of the pipeline after the restoration operation by alternative trenchless methods.

1 Introduction

The authors [1-3] consider automated design as an integral part of the digitalization of urban construction and one of the urgent tasks of national importance. This aspect corresponds to the tasks of construction, operation, repair and modernization of municipal pipeline transport to create optimal human living conditions and ensure environmental safety of the region [4].

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Potential tasks for effective design, construction, operation, and reconstruction of pipeline networks:

- computer modeling of gravity drainage network operation using automated programs to improve the design, including in the presence of foul-smelling gases (FGS) in the underwater space of pipelines [5-6];
- analysis of repair-rehabilitation methods for dilapidated pipelines with the choice of the optimal variant from among the alternatives based on estimated calculations [7-8];
- selection of apparatuses for nodes of drainage networks for optimal costs during pipeline renovation [9].

Computer simulation is the basis for selecting the optimal technical solution for several hydraulic and aerodynamic parameters of pipeline system operation. It considers, for example, such indicators fixed by gas analyzers as gas emissions (hydrogen sulfide, methane, mercaptans, etc.), excessive concentrations of which in the underwater space of the pipeline, and their release into the atmosphere through the sewage wells can be harmful to human health. Thus, the maximum permissible concentrations of each of the harmful substances in the city's atmosphere are subject to accounting. Automated programs determine the timing of the removal of gases from the pipe system to values below the maximum allowable in the atmosphere by organizing air exchange with the definition of the type of discharge system of ventilation of the underflow space. The selection of ventilation units provides the latter.

2 Materials and methods

The material of the study is a calculated section of a dilapidated gravity drainage pipeline with a length of 300 m and a slope of 0.0025, made of chrysotile cement pipes with a diameter of 400 mm. The groundwater is 2.5 m deep from the vault, which is 5 m below the surface. The dilapidated pipeline has many defects as pipe joints in couplings, which lead to significant leaks.

According to the readings of the sensor gas analyzer "Senson-SD-7031" the initial concentration of hydrogen sulfide in the underwater space of the network section is 4.2 mg/m^3, and the standard maximum permissible in the city atmosphere - 0.008 mg/m^3.

Let's consider three solutions as alternative trenchless technologies for pipeline renovation: application of Scotchkote spray coatings; pulling through the pipeline of a pre-compressed (deformed U-shaped profile) polyethylene pipe with an outer diameter of 355 mm SDR 26 by a braid from a reel; application of a protective coating by pulling through the pre-compressed by thermomechanical method (Swage Lining) of polyethylene pipe with an outer diameter of 450 mm (SDR 17).

The estimate of repair measures includes assessment of cost parameters of preparatory, main and final construction and technological operations: mechanical cleaning of inner surface of the drainage pipeline, organization of water dewatering of groundwater level above the pipeline, television inspection of the pipeline after rehabilitation operation. We have made cost-estimate calculations for the pipeline's reconstruction using the professional automated program "Stroyinformresurs" with the current prices and the indexes of overhead cost norms and estimated profit as of February 2023.

The tasks of the automated complex operation included the study of the dynamics of changes in the duration of removal of malodorous gases from the underlying space of the pipeline to their values below the maximum permissible in the atmosphere of cities after the reconstruction work [10].

3 Results and discussions

The last results of the estimate contain Table 1.

Table 1. The comparative estimated cost of repair work on the reconstruction of the pipeline by alternative methods, considering the preparatory, basic, and finishing work.

Repair technology	Cost, rubles
Application of continuous coating by dragging a pre-compressed (deformed U-shaped) polyethylene pipe with an outer diameter 355 mm (SDR 26) in a braid coiled from a reel	3 992 912.352
Application of Scotchkote spray coatings	3 757 445.824
Solid coating of thermo-mechanically pre-compressed (Swage Lining) polyethylene pipes 450 mm in diameter (SDR 17)	5 084 949.55

Table 1 shows that the most expensive method of reconstruction is the application of continuous coating by pull-through pre-compressed thermomechanically (Swage Lining) of polyethylene pipes with a diameter of 450 mm (SDR 26).

Below, we present the results of automated calculations on the neutralization of DPG using each of the presented technologies of trenchless repair.

After pipeline reconstruction works, the internal diameters change to:

- 400 mm for the Scotchkote spray coating (as the thickness of the layer is tiny and is not over 3 mm);

- 300 mm with some technological reserve towards reduction in the diameter while dragging the polyethylene pipe of U-shaped profile of 355 mm and two wall thicknesses, i.e. 13.6x2=27.2 mm;

- 300 mm with some technological reserve towards decrease, as during pulling through the pre-compressed pipes of 450 mm in diameter with subsequent straightening, the diameter is 358.6 mm (for SDR 17). The calculation is made using an automated program [11].

Automated calculation of water-air mode of pipeline operation during implementation of the three above repair technologies we carried out with the help of software complex "Modeling of water-air mode of operation of non-pressure drainage networks".

An analysis of the results of the automated program's operation under the conditions of a nonuniform operation mode of a drainage network during a day (i.e. with different filling h/d from 0.1 to 0.9) was reduced to choosing an optimum design of a ventilation unit in the initial (in the course of a precise liquid flow) sewage manhole. We took as the final well at a distance of 300 m from the initial one (i.e., at the end of the calculation section).

Analysis of automated calculations consisted in the nature's study of the curves of the function T=f(h/d) in Fig. 1. It shows the dynamics of change in the air exchange rate from the time of gaseous impurities removal for three reconstruction options and a certain air exchange rate (in this case, 0.003 m^3/s).

The curves T=f(h/d) have the same character, differing in the value of time of neutralization of gases by their dilution with atmospheric air. We note that at values of fills h/d from 0.6 to 0.9, the values of times T change insignificantly (between 1-1.5 minutes).
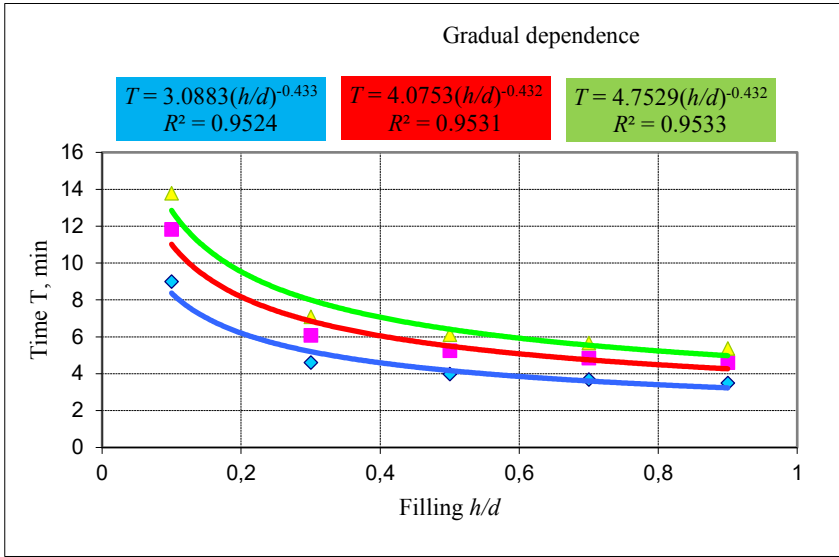
Fig. 1. Graphical dependencies describing the dynamics of changes in the time (T) of pollutant removal from the filling (h/d) (blue - for chrysotile cement pipeline with Scotchkote coating, red - for polymeric U-pipe, and green - with a pre-compressed polymeric pipe by Swage Lining technology).

To achieve the goal, i.e. to select the optimal design of the ventilation unit, we have plotted (based on the results of the automated complex) the dependencies of time change T on various values of air exchange QB at the calculated water filling in the pipeline h/d=0,6 for three options for reconstruction of the design section length of 300 m (Fig. 2). The range of air exchange rates QB was chosen in a wide range of 0.003 - 0.035 m³/s.
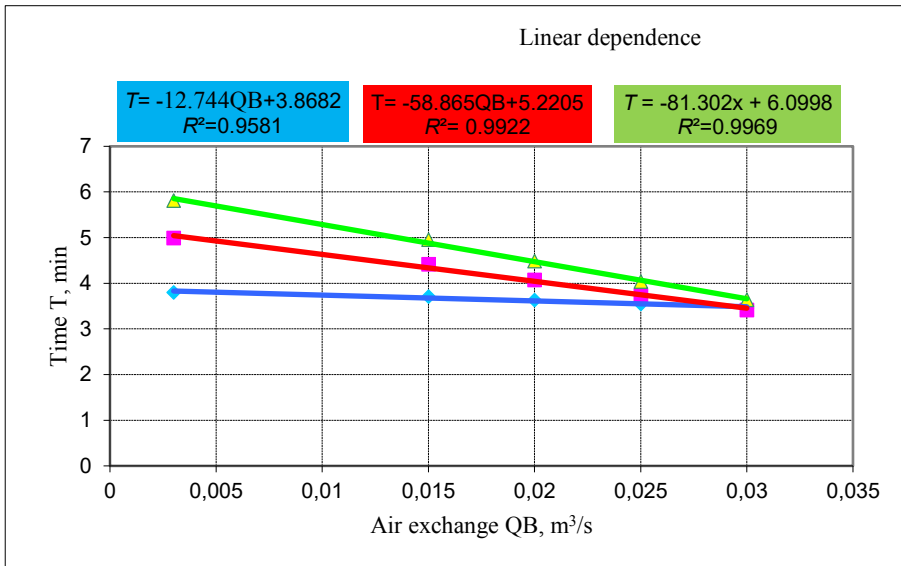

Fig. 2. Graphic dependences T=f(QB) (blue - for Scotchkote-coated chrysotile cement pipeline, red - for polymer U-pipe, and green - with pre-compressed polymer pipe using Swage Lining technology).

Analyzing the dynamics of changes in air exchange parameters in Fig. 2, we can note the character of curves of function T=f(QB) described by linear dependence with their approximate point of convergence near values of air exchange QB=0.03 m³/s. We can

consider such value as a basic (universal) one for solution of a particular task of piping reconstruction and it is taken as an optimum one for the selection of a ventilation unit capacity.

Technical and economic solutions can help to save money. It is necessary to carry out reconstruction of the old pipeline section by the method of continuous covering by dragging pre-compressed (deformed polyethylene pipe of U-shaped profile) with an outer diameter of 355 mm SDR 26 with a braid coiled from a reel; the value of air exchange is taken equal to 0.03 m^3/s (108 m^3/h), which satisfies all the options of pipeline section reconstruction with the trenchless repair to the same extent.

The described approach (algorithm) should be applied for each problem of reconstruction of old pipelines in the presence of foul-smelling gases in their underwater space. It is necessary to consider dimensions of the gravity pipeline system (diameter, length, manufacturing material, etc.), and information about foul-smelling gases concentrations (specifically for each harmful and aggressive gas) in the underwater space and maximum permissible concentrations in the city atmosphere recorded by operation services. By successive selection from the array of values of productivity of various ventilation units, the value of the optimal air exchange close to the results of the automated calculation is assigned.

We must make ventilation units and other equipment of the sewage manhole of materials resistant to corrosive gases with protecting at least IP44. We equipped ventilation equipment in the initial manhole with a speed regulator and an automatic time-to-start. In the drainage branch in the upper point, a flap is installed to direct the flow of pressurized air at the flow of wastewater. At the end of the site, we install an exhaust riser with a minimum height of 5 meters, in places where there are no people.

To solve the problem, we can pick up the fans of domestic production firms ESQ, Vertro and Era with an air exchange rate equal to 150 m^3/h, 250 m^3/h, 350 m^3/h. Explosion-proof ventilators of domestic production manufactured by the Serpukhov Electromechanical Plant (SEMP) and Klimatventmash with the minimum possible air capacity of 300 m3/h can also be used. Ventilated gravity flow pipeline should have sealed covers on sewer manholes throughout the aerodynamic section to avoid the release of foul-smelling gases on the ground surface.

4 Conclusions

1. The authors planned the tasks of optimizing the design of repair-restoration work and operation of dilapidated gravity-flow pipelines in conditions of an increased gassiness of their underwater space based on a discrete approach (i.e. for the most damaging section because of multiple defects and a significant excess of foul-smelling gases concentrations in the underwater space).

2. Developed and implemented an approach (algorithm) for decision-making based on:
- carrying out estimated calculations on the application of alternative technologies for the repair of dilapidated pipelines;
- automated design in case of the presence of foul-smelling pipeline sections in the underwater space. This includes considering dimensions of the gravity pipeline system (diameter, length, material of manufacture etc.), information on concentration of foul-smelling gases (for each harmful and aggressive gas) in the underlying space and the maximum permissible concentration in the city's atmosphere.

3. Presented recommendations for the use of ventilation units and equipment in the sewer manhole and their types.

References

1. A. P. Dobrynin, K. Yu. Chernikh, V. P. Kupriyanovsky, Int. J. of Open Information Technologies **1(4)**, 4-10 (2016)

2. V. P. Kupriyanovsky, S. A. Sinyagov, ArcReview **2(73)**, (2015)

3. T. Tatarinov, CAD and Graphics. Architecture and Construction **2**, 11–15 (2018)

4. S. V. Khramenkov, *Time to manage water* (Moscow, OAO Moscow textbooks and cartolithography, 2012)

5. S. V. Fedorov, V. M., Vasiliev, A. M. Telyatnikova, Bulletin of Civil Engineers **2(67)**, 168-174 (2018)

6. M. V. Bogomolov, F. V. Karmazinov, S. V. Kostyuchenko, Water Supply and Sanitary Engineering **7**, 33-43 (2016)

7. T. Wells, R. E. Melchers, Cement and Concrete Research **77**, 82-96 (2015)

8. S. V. Khramenkov, O. G. Primin, V. A. Orlov, *Reconstruction of pipeline systems* (Publishing house DIA, 2008)

9. G. Westerman, D. Bonnet, A. McAfee, *Leading Digital: Turning Technology into Business Transformation* (Harvard Business Review Press, 2014)

10. V. A. Orlov, S. P. Zotkin, A. P. Storozhev, V. A. Gerasimov, O. V. Melnik, *Modeling of the water-air mode of operation of non-pressure drainage networks*, Certificate of the Russian Federation on state registration of a computer program No. 2020614973.2020

11. V. A. Orlov, S. P. Zotkin, *Calculation of the operation parameters of pipelines restored by pre-compressed polymer pipes*, Certificate of the Russian Federation on state registration of the program on a computer No. 2014612753.2014