Research on factors affecting the operational reliability of water and sewer utility networks

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Abstract. Factors affecting the operational life of the water supply and sewer utility networks have been investigated. A method has been proposed for identifying the main factors affecting the operational reliability of distribution networks, which is based on the use of the expert evaluation method. It has been found that the most affecting factors are: pipeline material; corrosion of pipe and joint materials due to the corrosive environment; technical condition; service life; non-compliance of pipe grades to design value; ambient operation conditions. A more in-depth study of the issue will allow operating companies to promote the extension of the operation life of distribution networks.

1. Introduction

The distribution system of water and sewer utility networks is a sophisticated complex of facilities for conveying drinking water of the required quality and in the required quantity; for sustainable wastewater disposal. Its key elements include water mains, sewers and networks of various diameters, which describe the degree of urban development and improvement [1].

Under current conditions, Ukrainian operating companies carry out their activities on the verge of their technical and organizational capabilities, as evidenced by the high depreciation of fixed assets and emergency condition of a large part of networks in the context of inadequate funding of the industry. This leads to a decrease in the quality of drinking water, which is unacceptable in terms of public health protection in Ukraine primarily from the point of view of bringing the physicochemical parameters of water quality to the standards of the European Union.

The purpose of the work is to investigate into factors affecting the operational reliability of the water and sewer utility networks.

According to the stated purpose, the main objectives of the work are:
- To review the current state of distribution networks of the water and sewer utilities in Ukraine, including Kharkiv;
- To investigate into factors affecting the operational reliability of the water and sewer utility networks;
- To identify the main factors which most affect the operational life of the water supply and water disposal networks using the expert evaluation method.
Research methods: bibliographical retrieval, analysis and systematization, analysis and generalization, classification, expert evaluation, ranking.

2. Related research

Over the last two decades, the issue of research into the effective operation and repair of damage to water supply and water disposal networks has been the subject of multiple studies by domestic and foreign scientists. In this field, the most significant are the works by D.F. Goncharenko [2-6], T. A. Kostiuk [7], A. A. Garmash [8], V.O. Orlov [9] and others [10-16]. Research by German scientists on the operational reliability of pipelines clearly shows that currently, priority is given to no-dig rehabilitation solutions [12, 13], which are more cost-effective than conventional techniques (involving earthwork operations). The work by D.Stain [12] consolidates the results of many years of research into the causes of pipeline failure, the impact of their technical condition on water quality, and ways to extend their service life. The works by foreign scientists [11, 14, 15] cover modern approaches to the study of the extension of the operation life of water supply and water disposal networks.

However, enhancing the operation of pipelines of various purposes, improving their reliability is an important, but not yet fully resolved issue, so there is an urgent need to develop organizational and technological solutions for the smooth operation of underground utility networks of water and sewer utilities in accordance with domestic operating conditions. In this respect, particular attention should be paid to the study of factors affecting the operational reliability of water supply and sewer utility networks.

As of 2015, the length of water supply and water disposal networks in Ukraine was 106,374 and 37,404 thousand km respectively, of which 36,185 thousand km or 34 % of water supply networks and 12,749 thousand km or 34 % of sewer networks being in an emergency condition [1]. In comparison with 2014, for the country as a whole there was a decrease in the length of emergency water supply networks by 3,698 km or 3.4 % and an increase in the length of emergency water disposal networks by 459 km or 3.6 %. In the period of 2005 to 2011, the length of emergency networks increased annually: water supply networks by 3,698 km or by 0.9 % and sewer networks by 400 km or by 0.9 %. In the meantime, this trend has changed since 2012; water supply networks showed a decrease in the number of emergency networks by an average of 1.2 % per year whereas sewer networks had an increase in the number of emergency networks by 0.67 % per year [1].

One of the most important tasks to be carried out by urban facility maintenance services is to prevent ageing and promptly to remedy the consequences of an emergency. Currently, this issue is of particular relevance in Ukraine, where in the utilities sector, the ageing of distribution pipelines and other equipment of various purposes has reached a critical level [2, 3].

The term “operational reliability” refers to the ability of a facility to remain functional until the limit state is reached (after which intended use is inadmissible or inappropriate) with a maintenance and repair system put in place.

Under conditions of insufficient funding and a high degree of degradation, the distribution system of centralized supply and conveyance of drinking water and wastewater disposal is the most significant element of the complex of facilities of the water and sewer utilities.

The main reasons for the disruption of uninterrupted water supply through the supply and distribution system in Kharkiv are holes, cracks, and fractures in the water distribution networks. The main kind of damage to steel pipelines is spot through damage to the pipeline wall. It occurs as a result of spot corrosion. This type of corrosion is due to the thermodynamic instability of structural materials exposed to substances which are present in a contact medium [3, 6].

Normal operation of a water disposal network is often complicated by defects occurred during construction and by non-compliance with standard operating procedures for the use of public sewer utilities, which results in emergencies, the complete or partial cessation of the flow.
of sewage through the pipeline, and the penetration of sewage on the ground surface or in groundwater \[2\].

It should be noted that the largest amount of damage occurs to distribution networks, sewers and water lines laid out in 1960-1980 during the period of large-scale housing construction, the length of which is about 60 % of the total length of the pipelines. The situation is compounded by the wide use of steel, reinforced concrete structures, pipes with no corrosion protection, whose service life is too short, during laying out. This fact indicates that the issue of the durability and trouble-free operation of water supply networks will be of strategic nature before long.

3. Results and discussion

The author of the work reviewed the main factors affecting the operation life of water supply and water disposal networks. The factors were further grouped into the following groups on Table 1.

| Item No. | Group of factors | Affecting factors |
|---------|------------------|-------------------|
| 1       | Production factors (during pipe manufacturing) | – Wall thickness variations due to the displacement of the cast nugget, shrinkage holes of various types and sizes; – Typical defects occurring during the manufacture of pipes of polymer materials; – Deterioration in corrosion resistance and mechanical performance of pipes due to the use of low-quality material; – Insufficient corrosion protection; – Unsuitable pipe joint designs. |
| 2       | Factors of the durability of materials used for the line sections of a network | – Corrosion of pipe and joint materials due to the corrosive environment; – Fatigue and brittleness of artificial materials; – Degradation of organic materials; – Decrease in the stabilizing force of rubber seals. |
| 3       | Organizational and technological factors (during pipeline laying out and installation) | – General violations of the standard operating procedures for pipe installation; – Pipe butt joints made with procedural violations; – Errors during pipe storage and transportation; – Insufficient protection of the inside and outside of the pipeline from corrosion; – Errors during pipe laying out and grounding. |
| 4       | Factors of the external operational environment | – Soil swelling and shrinkage due to natural conditions; – Increased transport loads; – Damage due to emergencies in neighboring networks; – Permanent settlement joints appeared on mountain slopes, in the areas of inclinations, on the banks of rivers with a strong flow of groundwater and in places with frequent changes in the groundwater level. |
| 5       | Operational factors | – Service life of the pipeline; – Fluid pressure drops in the pipeline; – Corrosion of pipe and joint materials due to the action of microorganisms; |
Based on the factors grouped together in Table 1 that affect the operational reliability of distribution networks, the author proposes a method for identifying the factors that most affect the reliability using the expert evaluation method.

To identify the factors which most affect the operational reliability of the water and sewer utility networks, a method was used which is based on expert evaluation [6, 16]. The factors were chosen from Table 1 as the most significant according to the author that affect the operational reliability of the line sections of distribution networks in the water and sewer utilities; each factor was assigned the symbols of X1 to X12 (Table 2). Expert evaluation had to be resorted to due to lack in sufficient number of statistical data on the priority of the factors affecting the operational reliability of the line sections of distribution networks in the water and sewer utilities [6, 16].

**Table 2.** Main factors affecting the operational reliability of the line sections of distribution networks in the water and sewer utilities.

| Item  | Factor                                                                 |
|-------|------------------------------------------------------------------------|
| X1    | Pipeline material                                                      |
| X2    | Service life                                                           |
| X3    | Corrosion of pipe and joint materials due to the corrosive environment |
| X4    | Physical and mechanical properties of soil                            |
| X5    | Non-compliance of pipe grades to design values                         |
| X6    | Errors during pipe storage and transportation                          |
| X7    | Ambient operation conditions (presence of wandering currents, transport loads, lack of grounding) |
| X8    | General violations of the standard operating procedures for pipe installation |
| X9    | Technical condition (availability of damage statistics for a given period, damage control and recovery methods) |
| X10   | Fluid conveyance conditions (pipeline pressure drops, wastewater conveyance) |
| X11   | Typical defects during pipe manufacture                                |
| X12   | Violations of the pipe connection procedure                            |

The method involves obtaining expert evaluations in tabular form for the factors affecting the operational reliability of the line sections of distribution networks in the water supply and sewer utilities, and obtaining data on the most affecting factors.

The first stage of the method is about to rank the factors in order of increasing or decreasing any of their inherent values. When ranking, an expert arranges the factors in the order that they deem to be the most rational and assigns ranks to these. In this case, rank No. 1 obtains the
highest level of influence when choosing a method for rehabilitating a pipeline whereas rank No. N has the lowest. Consequently, the ordinal scale obtained as a result of ranking is to meet the condition where the number of ranks “12” is equal to the number of ranked factors “n”. Further, a summary table of ranks was compiled for all experts of the group (Table 3) [6, 16].

Table 3. Findings of the survey of experts included in the group.

| Factor | Expert | Sum |
|--------|--------|-----|
|        | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| X1     | 3  | 3  | 2  | 1  | 2  | 2  | 3  | 1  | 2  | 1  | 20  |
| X2     | 4  | 4  | 3  | 4  | 5  | 6  | 4  | 5  | 4  | 4  | 43  |
| X3     | 2  | 1  | 1  | 2  | 1  | 1  | 2  | 2  | 1  | 1  | 14  |
| X4     | 10 | 9  | 11 | 8  | 11 | 7  | 8  | 11 | 10 | 9  | 94  |
| X5     | 7  | 6  | 5  | 5  | 6  | 5  | 6  | 6  | 5  | 5  | 56  |
| X6     | 11 | 11 | 12 | 10 | 12 | 10 | 11 | 10 | 12 | 12 | 111 |
| X7     | 6  | 5  | 6  | 4  | 4  | 5  | 4  | 6  | 5  | 5  | 51  |
| X8     | 9  | 8  | 10 | 11 | 10 | 11 | 10 | 8  | 11 | 10 | 98  |
| X9     | 1  | 2  | 3  | 2  | 2  | 3  | 2  | 1  | 1  | 1  | 21  |
| X10    | 8  | 7  | 8  | 9  | 8  | 7  | 9  | 9  | 8  | 7  | 80  |
| X11    | 5  | 5  | 7  | 7  | 6  | 6  | 5  | 6  | 7  | 6  | 60  |
| X12    | 8  | 10 | 9  | 7  | 8  | 7  | 7  | 9  | 8  | 8  | 80  |
| Sum    | 74 | 71 | 77 | 73 | 74 | 70 | 71 | 70 | 77 | 71 |      |

Since in some cases the ranks given by the experts to one evaluated factor or another coincide, a rank scaling was performed, which is calculated according to the classical calculation method [6, 16]. After standardization and calculations of all standardized ranks, a table was elaborated (Table 4).

Table 4. Findings of the survey of experts included in the group with regard to the scaling.

| Factor | Expert | Sum |
|--------|--------|-----|
|        | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | Sum |
| X1     | 3.2 | 3.3 | 2  | 1.1| 2.1| 2.2| 3.3| 1.1| 2  | 1.1| 21.4|
| X2     | 4.2 | 4.4 | 3  | 4.3| 3.3| 6.7| 4.4| 5.6| 4  | 4.4| 46.3|
| X3     | 2.1 | 1.1 | 2.1| 1.1| 1.1| 1.1| 2.2| 2  | 1  | 1  | 15  |
| X4     | 10.5| 9.9 |11.1| 8.5| 11.6| 7.8| 8.8| 12.3|10.1| 9.9|100.6|
| X5     | 7.4 | 6.6 |5.1 | 5.3| 6.3 | 5.6| 6.6| 6.7 | 5.1| 5.5| 60.1|
| X6     | 11.6| 12.1|12.2|10.7|12.6|11.1|12.1|11.1|12.2|13.2|118.9|
| X7     | 6.3 | 5.5 |6.1 | 6.4| 4.2 | 4.5| 5.5| 4.5 | 6.1| 5.5| 54.5|
| X8     | 1.1 | 2.2 |3.2 | 2.1| 2.1 | 3.3| 2.2| 1.1 | 1  | 3.3| 105 |
| X9     | 8.4 | 7.7 |8.1 | 9.6| 8.4 | 7.8| 8.9| 8.1 | 7.7| 22.6|
| X10    | 5.3 | 5.5 |7.1 | 7.5| 6.3 | 6.7| 5.5| 6.7 | 7.1| 6.6| 85.8|
| X11    | 8.4 | 11  |9.1 | 7.5| 7.4 | 8.9| 7.7| 7.8 | 9.1| 8.8| 64.2|
| X12    | 9.5 | 8.8 |10.1|11.8|10.5|12.3|11.0| 8.9|11.1|11.0|85.7 |
| Sum    | 78  | 78  |78  | 78 | 78  | 78 | 78 | 78  | 78 | 78 |      |

At the second stage, the coefficient of concordance W was used to define the consistency of experts’ evaluation [6, 16].

According to the analysis of the table of standardized ranks and the performed calculations, the coefficient of concordance equal to 0.828 was obtained, which indicates a high degree of consistency of opinions in the selected group of experts (Figure 1).
Figure 1. Diagram of the summed ranks of the investigated factors according to the expert evaluation findings.

From the obtained diagram, one may conclude that of the above 12 factors, the highest degree of impact on the choice of the type repair and rehabilitation work to be performed is exerted by factors X1, X3, X9 (the summed rank of these phenomena is minimal), along with factors X2, X5, X7. The most significant factors are:

- Pipeline material;
- Corrosion of pipe and joint materials due to the corrosive environment;
- Technical condition (availability of damage statistics for a given period, damage control and recovery methods;
- Service life;
- Non-compliance of pipe grades to design values;
- Ambient operation conditions (presence of wandering currents, transport loads, lack of grounding).

It should be noted that only a comprehensive study of the above factors will make it possible in the future to minimize the impact of each of them, thereby ensuring the extension of the operation life of the water and sewer utility networks.

4. Conclusion

Given the strategic directions of the development of maintenance services of the water and sewer utilities in Ukraine, improving the durability of the distribution system by developing new techniques for its repair and rehabilitation will allow achieving its smooth operation. As a result providing services of uninterrupted supply of drinking water and water disposal to ensure high standards of living for the population.

For this challenging, complex issue, factors affecting the operational life of the water and sewer utility networks were investigated, and a method for identifying the above factors based on the expert evaluation method was proposed. It has been found that the most affecting factors are as follows: pipeline material; corrosion of pipe and joint materials due to the corrosive environment; technical condition; service life; non-compliance of pipe grades to design value; ambient operation conditions. A more in-depth study of the issue will allow operating companies to promote the extension of the operation life of distribution networks.
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