RESEARCH METHODOLOGY OF WATER NETWORK FAILURE IN TERMS OF RENEVAL

METODOLOGIA BADANIA AWARYJNOŚCI SIECI WODOCIĄGOWEJ W ASPEKCIE JEJ ODNOWY

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Abstract: *The important and crucial issue concerning water supply functioning in terms of conducting failure analysis were discussed. In the work failure indicators, water losses and availability of water services, that define standards of quality water services and their values were determined based on data from exploitation. In order to understand the current situation of water supply infrastructure it is necessary to perform periodic analyzes of water supply network failure, which was proposed in this paper. A detailed analysis of the failure and the water loss of the water supply network should be the main element of the urban management water supply network, particularly in the strategic plans for its modernization.*

Keywords: *water supply infrastructure, failure indicators, water losses and availability of water service indicators, renewal planning*

Streszczenie: *W pracy omówiono kluczowe zagadnienia dotyczące zaopatrzenia w wodę w zakresie prowadzenia analizy awaryjności sieci wodociągowej. Przedstawiono wskaźniki opisujące awaryjność, straty wody oraz dostępność usług wodociągowych oraz wyznaczono ich wartości w oparciu o dane z eksploatacji. W celu poznania bieżącej sytuacji infrastruktury wodociągowej konieczne jest przeprowadzanie okresowo analiz awaryjności sieci wodociągowej, które zaproponowano w tej pracy. Szczegółowa analiza awaryjności oraz strat wody występujących w sieciach wodociągowych, powinny być głównym elementem systemu zarządzania miejską siecią wodociągową, a w szczególności uwzględnione w strategicznych planach jej modernizacji.*

Słowa kluczowe: *infrastruktura wodociągowa, wskaźniki awaryjności, wskaźniki strat wody oraz dostępności usług wodociągowych, planowanie odnowy*

1. Introduction

Water supply systems (WSS) are being operated in a continuous manner for a long time. Therefore the elements building them are also subject to intensive exploitation. Damage of the object or device usually entails the necessity of exclusion it from the operation in order to remove a failure. It causes economic consequences for the water supply company (Rak 2014), resulting from the reduction or interruption of water supply. For this reason, to make appropriate service (repair, renewal, replacement) only after the damage of the element can be irrational (Pietrucha-Urbanik and Tchorzewska-Cieslak 2014). Human interference detects and removes defects that are a potential source of failure (Shamir and Howard 1979; Vloerbergh and Blokker 2010).

After several decades, the trend of the increase in the intensity of damages of water pipes associated with ageing, is observed (Nishiyama and Fillion 2013; Rak and Tchorzewska-Cieślak 2007). In such cases, we face the alternative to repair the increased number of failures or to carry out technical renewal of pipelines through major overhauls (Rak 2009).

A commonly used solution become the prophylactic renewals aimed at reducing the rate of loss of usability of the element (Carey and Lueke 2013). The prophylactic renewals do not eliminate the possibility of damage, but they can reduce the likelihood of the emergency renewals (Nafi and Kleiner 2010). Strategy of the prophylactic renewals means to perform them in proper time, in order to achieve maximum profitability of the project or the required level of reliability, using, for example, periodic strategies involving the prophylactic renewals after a predetermined operating time of each element and the emergency renewals as soon as the element is damaged (Glowacz 2012; Herz 2008; Le Gat and Eisenbeis 2000, Rak 2003).

For losses resulting from the failure of water pipes the following areas of occurrence can be distinguished (Tchorzewska-Cieślak and Pietrucha-Urbanik 2013):

- in relation to waterworks companies: losses resulting from the repair of failure, including the costs of preparing for the repair, its execution, return of segment to service and restoration of the area to its original state; losses associated with the volume of water which was not sold because of the failure - it can be estimated as the average water consumption during the failure, additional losses resulting from the failure, such as the costs of the removal of flooding, changes in traffic organization, etc., costs arising from the responsibility of waterworks company towards water consumers, for example, penalties for lowering the standards of water supply; costs associated with keeping the maintenance service in readiness,
- in relation to water consumers: costs associated with the lack of water supply - for industry and services they are understood as, for example, the value of reduction of production or production of lower quality goods, for housing they are more difficult to estimate, the valuation may be performed by the discretionary methods; costs of the loss of health resulting from difficulties in the maintenance of hygiene; potential costs associated with the inability to use tap water to extinguish fires.

The act on collective water supply and collective sewage disposal (based on Article 19, paragraph 2) and regulation on the quality of water intended for human consumption impose an obligation to adopt the rules defining the rights and obligations of the water supply company and the recipients of the services.

The regulation concern:

- a minimum level of services provided by the company for the water supply,
- the detailed terms and conditions for contracts with the recipients of the services,
- the method of accounting based on the prices and charges set out in the tariffs,
- the conditions for connecting to the network,
- technical conditions defining the possibility to get the access to the water services,
- the course of action when the service is not continuous and water does not have proper parameters,
- a level of service to the recipients of the services, and especially the ways of handling complaints and the exchange of information on disruptions in water supply.

However, legal regulations regulating the operation of water supply companies and conditions of receiving water have certain deficiencies (Pietrucha-Urbanik 2014). One example is the lack of clear rules that would strictly define minimum level of services provided to water customers by water companies. Therefore a research methodology is proposed in this paper concerning future overhauls of water network.

2. Research of water supply network failure

Current issue of water network failure analysis

Failure analysis constitute the main source of information needed to perform the water network modernization (Kwietniewski et al. 1993; Kwietniewski and Rak 2010; Tchórzewska-Cieślak 2011):

Failure assessment of water network, its strategies and techniques should consist of the following components:

- failure analysis, eg.: threat identification and determination of the possibilities of undesirable events,
- failure administration - documentation of failures and all the negative events in the water supply network also developing of emergency response plan and maintenance and modernization schedule, etc.
- cost and financing analysis, as to cover the expenses connected with execution of mentioned above processes, as well as to finance insurance systems, must be guaranteed in waterworks budget.

Generally in Poland causes of failure of water supply network can be distinguished in the following way presented in the Fig. 1.

Fig. 1 Factors influencing the water supply network failure in %

In reference to previous mentioned issues the database on failures can be divided into following groups (Mays 1989):

- general information about the objects (addresses, dates, etc.),
- technical data about the objects (types of objects considering their functionality, construction, technology, etc.),
- data on failure (type of event, cause, etc.),
- data on the effects and consequences of failure (type, scope of damage, causes, etc.),
- additional information.

Seven major group should be developed in terms of conducting failure analysis (fig. 2).

Fig. 2 Elements of a typical water network collected failure data

Failures in the water network can be a consequence of technical factors, human activity or weather/environmental phenomenon:

- improper ground conditions,
- wrong conception of water-pipe network geometry and structure,
- badly performed hydraulic calculations, incorrect water-pipe diameter, incorrect pressure in network,

- as concerns the technology of pipe laying,
- improper anticorrosion protection,
- badly performed pressure test and other procedures,
- incorrect operating procedures, a lack of water pipeline operation monitoring,
- lack of programme to classify the network segment requiring the repair,
- lack of programme to obtain, process and storing the data on failures; causes, consequences and records of data about failures.

Some examples of water supply network failures which covered some of the mentioned factors are as follows (in brackets time of delivery lack of drinking water were presented):

- damaging the main pipe during the redevelopment of the street, Wrocław (29.05.08),
- the failure of the main pipe because of the corrosion and bad technical condition, Wrocław (12.05-14.05.08),
- the failure of the main pipe because of too high pressure, Wrocław (31.07.08),
- the failure of the main pipe because of the effect of using up the material, Szczecin (3.01.09).
- the acts of vandalism, devastation of the wire linking the main well with the compensatory container, Strzyżów (15.10.98),
- destroying the pipeline supplying water from the well to water treatment plant as by moving aside escarpments as a result of the flood, Dąbrówka near Łańcut (31.07-8.08.04).

3. Indicators defining the availability, failure and losses in water supply

The crucial indicators used to estimate the availability and failure in water supply (Kwietniewski et al. 1993; Kwietniewski and Rak 2010; Tchórzewska-Cieślak 2011):

- number of failures in the assumed time interval,
- the average operating time between failures T_p [d],
- the mean repair time T_n [h] is interpreted as the expected value of time from a moment of failure to a moment when an element is included to the operation. It is the sum of the waiting for repair time T_d and the real repair time T_o (till the inclusion of the element to the operation),
- the time of interruptions in water supply to customers,

- the failure rate $\lambda(t)$ [number of failures $\cdot$ km⁻¹ $\cdot$ a⁻¹] is calculated for linear elements as the total number of failures in the time interval $(t, t + \Delta t)$ per length of linear elements L [km] in the given time of observation Δt ,
- the repair rate $\mu(t)$ [number of repairs $\cdot$ a(h)⁻¹] determines the number of failures repaired per time unit,
- the frequency of failures f is calculated as the average number of failures (damages, undesirable events) per time unit during the operation [failure/s, failure/month],
- System Average Interruption Frequency Index - SAIFI. This type of indicator is calculated by dividing the number of water consumers exposed to the consequences of this kind during the year by the total number of supported users. This indicator does not include interruptions in water supply shorter than two hours,
- ASAI - it is the quotient of the time of the continuous water supply throughout the year and the time when there was the demand for water.

The level of losses can be distinguished as the indicators of service quality level and water network conditions and can be distinguished in the following way:

- water loss rate per unit for the entire length of the line,
- unavoidable Annual Real Losses – UARL, is the annual volume loss, which is considered to be inevitable and economically viable. This means that the removal of small leaks do not cause significant water losses and damages in the vicinity of the water supply and greatly exceeds the material damage caused by these leaks,
- Infrastructure Leakage Index (ILI) is the ratio of the annual volume ratio of losses to UARL,
- Real Loss Benchmark (RLB) calculated as annual volume of water unsold per length of water pipeline.

Since the seventies, in many Polish centers, the research are being conducted related to the failure of water supply network. On the basis of this research standards have been developed, which are not mandatory, but facilitate the assessment and nevertheless regarded as a starting point for the assessment of the technical condition of water pipe (Hotlos 2003, 2007; Kwietniewski 2011; Kwietniewski et al. 1993, Rak 2005).

The required value of failure rate should not exceed in case of mains: $\lambda_{Mreq} = 0,3$ [no of failure/km $\cdot$ year], for distributional $\lambda_{Rreq} = 0,5$ [no of failure/km $\cdot$ year] and for water connections $\lambda_{Preq} = 1,0$ [no of failure/km $\cdot$ year].

4. Failure analysis and assessment of the collected data on the research example in the chosen water supply network

Based on the collected data from the selected municipality in the Podkarpackie Province we can formulate the following conclusions of the chosen and crucial indicators:

- in the case of the failure number in water supply network the largest number occurred in the water supply connections and the less on water supply network fittings,
- the average time between two subsequent damages to the distribution network is 8,5 [d] and for water supply connections 9,0 [d]. It states that the average operating time for network distribution and water supply connections have a similar value. In the case of water supply network fittings fail-safe state is approximately 21 [d], what indicates its low failure rate,
- the estimated time of repair only in a few cases exceed one working day (eight hours of work) and the intensity renewal rate is $\mu = 0,125$ [1/h],
- System Average Interruption Frequency Index equals 1.13 *number of failures* · 100 *recipients*⁻¹ · year⁻¹ and Average Service Availability Index - 0,962881 and the determined infrastructure leakage index ILI - 1,62. The technical condition of waterworks according to the IWA and AWWA can be described as good (Hirner and Lambert 2000; Mayer P. et al. 1999; World Bank Institute 2005),
- for the distributional pipe the value of the failure rate is $\lambda_{Ravg} = 0,15$ [*number of failures* · km⁻¹ · a⁻¹], for the water connections $\lambda_{WCavg} = 0,25$ [*number of failures* · km⁻¹ · a⁻¹] and water fittings 8,5 [*number of failures* · km⁻¹ · a⁻¹], the calculated failure rate comply with mentioned standards in third point.

5. Conclusion and perspectives

Water supply network is one of the most important technical underground system and is highly crucial for the livelihood and health of human being. An important role in the operation of water supply network constitutes failure analysis, based on the operating data, which in clearly way defines its technical condition.

It can be concluded that presented indicator of failure and losses of the examined water network is small and maintain on average level, as in comparison to other cities, what indicates about good condition of water network and is the result of investment and modernization projects performed in recent years, eg. modernization of the existing water supply network and running Active Leak Detection.

Limited period of operation of the water supply system should be planned on the basis of literature and operating data, according to the criterion of increasing failure

rate and loss of functionality, reduction in capacity due to incrustation and corrosive wear of the pipe.

Presented methodology, will be helpful and constitute the basis for so-called Water Safety Plans, recommended by WHO, which are obligatory for waterworks company and ensures water consumers safety.

Data from water authorities are received from exploiters of the water supply system. Calculated indicators in procedure of failure analysis suggested in the work were based on the mentioned above information. At present research are performed to establish failure criteria in order to perform repair and modernization.

4. References

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