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Impact of monitoring on the mean time to repair of the water supply network

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Abstract. The introduction of monitoring to a water supply network results in reducing its failure rate, increasing its reliability as well as improving the quality of water supplied to consumers, reducing water losses and increasing work safety in a water distribution system. Monitoring enables detection of leakages that could go unnoticed without this system, facilitates detection of leakages and location of failures, i.e. it shortens the repair time — or rather its component — the awaiting-repair time. This paper presents the results of the reliability analysis for a city located in the Upper Silesian Industrial Region before and after the implementation of monitoring to the water supply network.

1 Introduction

The main priority of every water supplying company is to guarantee its customers a continuous supply of water with the required quality, in the right quantity and under the appropriate pressure [1]. This is possible due to the use of the annular structure of the water supply network, which enables the multi-directional supply of water to the customers, and in consequence presents a high level of reliability [2]. Detecting and locating of failures in a large network of water conduits is difficult and time-consuming. An extensive monitoring system in the company makes this process much easier. Constant observation of pressure at selected points of the water supply network allows immediate reaction and verification in the case of their non-standard values, and thus provides the opportunity of quick identification of damages.

The system of detection, early warning and control of leakages in water distribution network enables efficient network management. The introduction of monitoring is the basis for creating this system in a water supply company [3].

Effective management of the water supply network is also influenced by its age and structure of pipe materials. Old water pipes break more often and leaks occur, which affects financial losses of the company [4]. Improving the reliability of the water distribution system, should be based on the systematic exchange of pipes with high failure rate and long service life for new ones, made of appropriate materials [5].

The reliability analysis of water supply networks and the introduction of monitoring should lead to cost optimization in the water supply company [6].

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The purpose of the articles is to examine the impact of monitoring on the reliability of water supply network, especially on reducing of mean time to repair (MTTR). The values of two reliability indicators were analyzed: unit failure rate, which describes the technical condition of the network, and mean time to repair, defining the rate of failure detection and repair. The presented research results confirm the positive impact of monitoring on network reliability. They also confirm the desirability of introducing monitoring in the analyzed distribution network.

1.1 The concept of reliability in relation to the water supply network

From the perspective of systems theory, the water supply network is a system. System classification defines it as an artificial system — created by man, physical, dynamic — its individual structural elements are changeable in time, and stochastic — it has random properties. In the case of a water supply network, these elements are the distribution and principal mains as well as service pipes . The attributes can be specified as material and diameter, and — in the case of conduits — also length. In order to determine the reliability of the network, it is necessary to analyze the reliability of system components. Each element can exist in two states: suitability (efficiency) to work and inability (inefficiency) to work. The transition from the state of suitability to the state of inability occurs when the object loses its properties, usually as a result of damage [7].

1.2 Quantitative assessment of the object's suitability

1.2.1 Unit failure rate

The analysis of operational data enables effective and rational management of works in the water distribution system. The key element of such analyzes is the determination of the unit damage intensity. It defines the number of failures related to the observation time and the average length of conduits. It is expressed by the following formula (1) [7].

$$\lambda(t) = n(\Delta t)/(L \cdot \Delta t) \tag{1}$$

where:

$\lambda(\Delta t)$ – unit failure rate, fail./(km·year),
$n(\Delta t)$ – number of failures in the period of time Δt,
L – average length of the examined conduits in the period of time Δt, km
Δt – period of time under consideration, years

This indicator is one of the main parameters describing the technical condition of the water supply network. The comparative analysis of the intensity of damages is carried out in order to properly operate the water distribution network and to appropriately manage the water supply company.

1.2.2 Mean time to repair (MTTR)

Repair time is one of the fundamental measures of reliability for renewable elements. It is expressed by the following formula (2) [7].

$$MTTR = (1/n_o) \cdot \Sigma t_{oi} \tag{2}$$

where:

n_o – Number of renewals (inabilities) in the analyzed time,

t_{oi} – Duration of the i-th renewal [h],

It consists of: the awaiting-repair time and the repair time itself. The length of failure removal time depends on the following actions [8]:

- Securing the place of failure,
- Notifying residents about shutting down the access to water,
- Cutting off the conduit in which the damage occurred,
- Performing an excavation,
- Repair: cutting out damaged parts of pipes, installing a new conduit, assembly of repair elements, etc.
- Rinsing and venting of the repaired section,
- Disinfection and leak test,
- Filling-in the excavation and soil compaction,
- Cleaning works.

The duration of these works depends — among other things — on: the season of the year, the material and diameter of the conduit, the type of soil and surface at the place of failure and the depth of the conduit's foundation.

The introduction of a monitoring system in a company significantly reduces the renewal time or actually the awaiting-repair time. Such system allows quick detection of leaks and enables determining their approximate location.

2 Characteristics of the examined network

The examined water supply network is supplied from a dozen or so purchase points and therefore it has been divided into sectors.

The sectors include individual city districts varying in area and length of the network, which are supplied from purchase points with different inflow pressures. Simultaneously with the introduction of monitoring, the pressure reduction valves (PRV) were installed in supplying points. Table 1 shows the pressure after the PRV and the length of the operated water distribution network sectors.

Table 1. The characteristic of analyzed sectors.

Sector	Pressure range after PRV [bar]		Length of the network [km]
	Before monitoring	After monitoring	
A	5.0–5.8	3.8–4.0	17.73
B	3.0–3.5	3.0–3.5	14.40
C	5.0–5.5	3.8–4.2	15.81
D	4.8–5.0	4.8–5.0	32.96
E	2.9–6.5	3.0–4.0	73.43
F	4.8–5.5	3.8–4.0	35.93
G	3.0–3.5	3.0–3.5	39.84
H	3.5–6.0	3.5–4.0	58.96
I	3.5–4.0	3.5–4.0	40.62
J	4.0–5.5	3.8–4.0	41.04

Sectorization of the network facilitates its exploitation and conducting of hydraulic monitoring. In the monitoring system of the analyzed network, water-meter wells were equipped with recorders for mobile monitoring with remote data and alert messages transmission via the GSM network. The devices record pressure and flow rate in each well.

Based on these data, the operation of the water supply network and minimal night flows are controlled at any time. Exceeding pressure and flow values — above or below the preset threshold — causes the recorder to generate information about the state of alert. Installation of recorders allows the hydraulic monitoring of the network, the diagnostic operations and controlling the operation of pressure reduction valves.

The analyzed network is located in one of Upper Silesian cities belonging to the Upper Silesian Industrial Region. Its water supply system encompasses 456.4 km of distribution networks. Over 71% of the total length of the network are distribution pipes, while house connections account for almost 26% of this value. The structure of water conduits is juxtaposed in Figure 1.

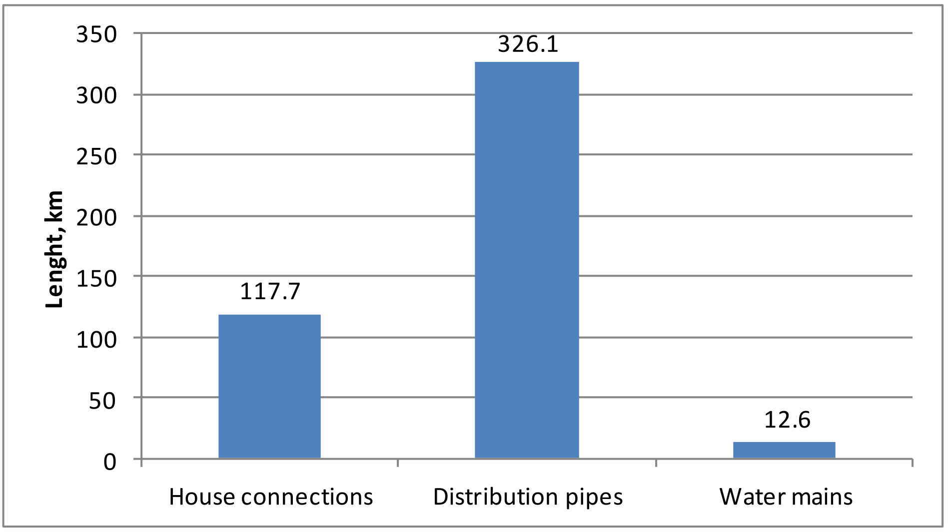

Fig. 1. Structure of water conduits.

Water conduits are made of PE, cast iron, steel and PVC. The material structure of the water supply network is shown in Figure 2.

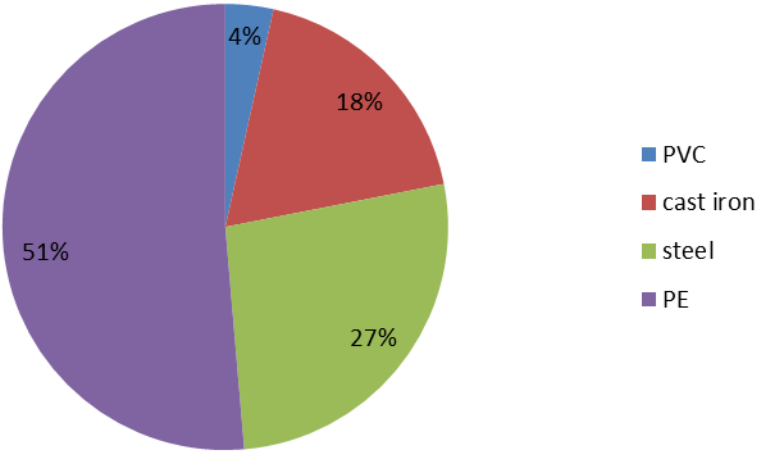

Fig. 2. Material structure of water conduits.

3 Presentation of results

3.1 Methodology

Operational tests of reliability of the municipal water supply network's conduits were carried out in the period from 2002 to 2013. The analysis of the water supply network was performed before the introduction of monitoring — in 2002–2007 — and after its introduction — in 2008–2013, based on archival documentation kept by the company. The value of one of the failure rate indicators — the unit failure rate λ (1) was calculated first. Then, taking into account the network sectorization, the value of the MTTR (2) was determined [8].

3.2 Unit failure rate before the introduction of monitoring

A total of 5807 damages were recorded in the analyzed period, including 1800 failures of service pipes and 4007 failures of the distribution and principal mains. The unit failure rate values in respective years of the research period are shown in Figure 3.

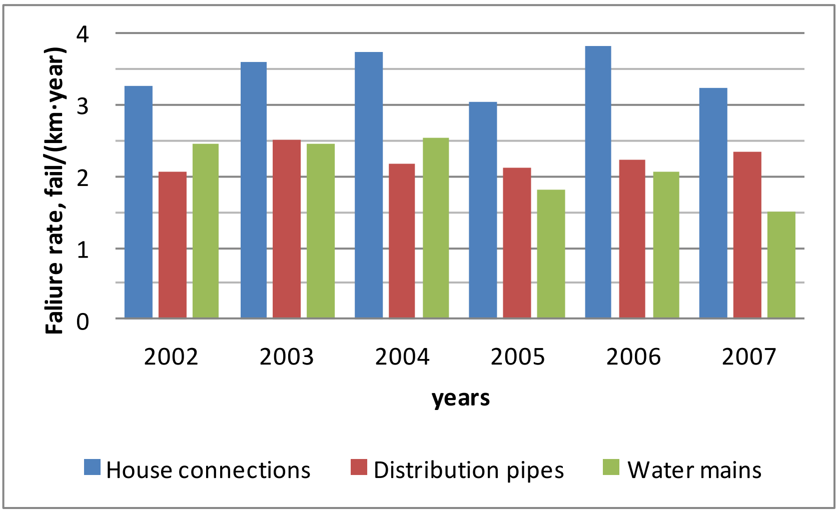

Fig. 3. Unit failure rate λ in the years 2002–2007.

The unit failure rate before the introduction of monitoring significantly exceeded the recommended levels for principal mains (λ<0.3 fail./(km·year)), distribution mains (λ<0.5 fail./(km·year)) and service pipes (λ <1.0 fail./(km·year)) [10].

3.3 Unit failure rate after the introduction of monitoring

The network's failure rate after the introduction of monitoring was analyzed next. The supplied data cover the period from 2008 to 2013. In the analyzed period there were a total of 3436 damages, including 2326 failures of the distribution and principal network conduits and 1110 failures of service pipes.

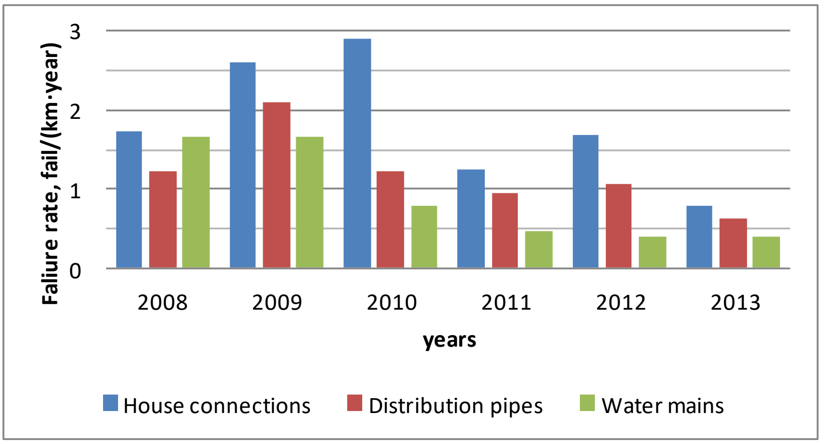

Fig. 4. Unit failure rate λ in the years 2008–2013.

At the beginning of the observation period, in the first 3 years after the monitoring was introduced, the unit damage intensity for all conduits increased rapidly because of the rise of damage detection efficiency level. Damages that would not have been identified earlier were detected relatively quickly. It allowed improving the technical condition of the network by replacing conduits with the highest failure rates.

Comparing the graphs for periods before and after the introduction of monitoring, one can notice after monitoring much lower values of the unit failure rate. These are not the literature values [10, 11] yet, but there is a significant improvement in reducing the number of failures. In the case of all types of conduits a continuous decrease in their failure rates from the year 2010 is noticeable.

3.4 Mean time to repair

The analysis of the MTTR [h] was performed for service pipes and jointly for distribution and principal mains, taking into account the network's sectorization.

Table 2. The mean time to repair in respective supply sectors.

Sector	MTTR [h]			
	2002–2007		2008–2013	
	House connections	Water mains and distribution pipes	House connections	Water mains and distribution pipes
A	13.8	18.0	9.8	12.9
B	12.7	10.4	8.7	8.3
C	11.0	16.1	11.2	15.8
D	15.8	12.5	7.0	14.3
E	21.8	22.6	11.0	14.8
F	23.1	22.7	6.7	16.4
G	29.5	13.9	8.4	9.5
H	18.6	14.0	6.3	10.9
I	11.0	11.0	7.5	13.6
J	14.1	15.5	9.1	11.8

In general, after the introduction of monitoring to the water supply network, the MTTR for all types of conduits has become significantly shorter. It can be noticed that the longest

MTTR for service pipes after the introduction of monitoring is about 11 hours, while before the introduction of monitoring it was the lowest value of this indicator. In the case of the distribution and principal network, the MTTR in almost every sector has been reduced (except D and I), but not to such a degree as in the case of service pipes. This is due to the fact that the repair of a service pipe is technically much simpler than in the case of distribution mains — not to mention the principal mains — because of the location of pipelines and their diameters. Additionally, the repair time itself in relation to the awaiting-repair time is in the case of service pipes much shorter than for the other conduits of the water supply network.

4 Conclusions

The analysis of reliability and the assessment of the water supply network's technical condition was based on the failure rate and mean time to repair. It allowed formulation of the following conclusions:

- The operational tests and reliability analysis conducted before and after the introduction of monitoring to the water supply network show a significant reduction in the failure rate for principal and distribution mains as well as for service pipes in the subsequent years of observation.
- Implementation of complete hydraulic monitoring in the examined water supply network, combined with its sectorization, enabled the on-going assessment of its technical condition due to the possibility of faster and easier identification of damages.
- The reduction of the failure rate during the subsequent years of water supply network operation is essentially related to the improvement of the network's technical condition, connected with the use of new material solutions (PE and SG iron), which was possible due to the implementation of the monitoring system.
- Operational tests performed in the years 2002–2007 and 2008–2013 show a significant decrease in the MTTR for the majority of analyzed sectors after the introduction of monitoring. The reduction of the MTTR in the subsequent years of the water supply system operation is mainly related to the implementation of the monitoring system — it shortens time from detecting the damage to its removal. Due to this fact, the duration period of the object's inefficiency decreases.

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