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Katarzyna PIETRUCHA-URBANIK[1]
Andrzej STUDZIŃSKI[2]
Politechnika Rzeszowska

FAILURE ANALYSIS OF THE KROSNO WATER NETWORK

In the article analysis of failures of the Krosno water network has been presented. In the work the analysis of the failure frequency for individual kinds of waterworks (main, distribution and water supply connections) on the example of the Krosno water network was also presented. An analysis based on exploitation data of the water network get from Municipal Services Office in Krosno in years 2005-2009 was carried out. In the work the analysis of the failures depended on the diversity of applied materials, age and diameters for individual kinds of waterworks was also presented.

1. Introduction

The Krosno water supply network covers an area of 11 municipalities of Krosno and Sanok counties (Besko, Chorkówka, Iwonicz Zdrój, Jedlicze, Korczyn, Krościenko, Miejsce Piastowe, Rymanów, Wojaszówka, Zarszyn and the city of Krosno). The water network supplies water to about 100 000 recipients of the city of Krosno and neighbouring municipalities. The number of residential water supply connections in all served places is 5 730, including 4 675 terminals located in the Krosno municipality. The scheme of the Krosno network is shown in Fig. 3.

The Krosno water pipeline is supplied with water from three water treatment plants (WTP), taking raw water from three independent surface water intakes, located on the river Wisłok in Sieniawa, Iskrzynia and on the river Jasiołka in Szczepańcowa. Water is provided to consumers via a water pipe network having radial-ring arrangement, which is beneficial to the reliability of water supply system. Currently, the water supply network has a total length of about 604,7 km. On the Fig. 1 and 2 a structure in division of the materials and the life of the water supply network are presented.

[1] kpiet@prz.edu.pl
[2] astud@prz.edu.pl

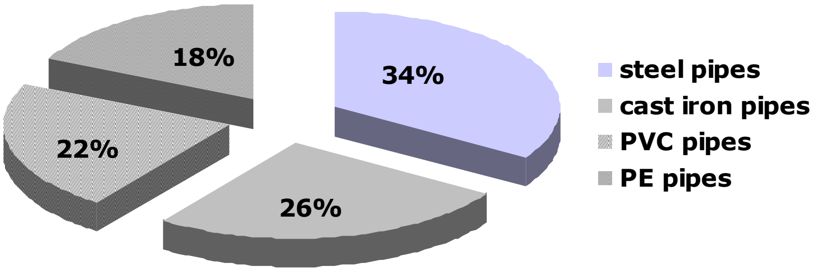


Fig. 1. The structure of the water supply network in division of the materials

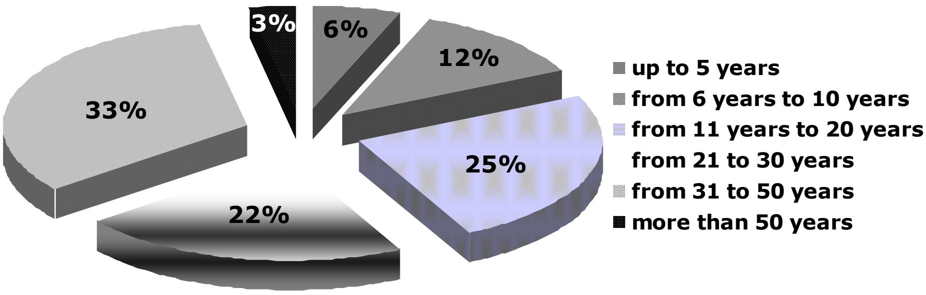


Fig. 2. The structure of the water supply network in division of the life

The purpose of this study is to characterize the unreliability of the Krosno water-pipe network. Detailed analysis of the water network failure, should be a main element of the managing system of the urban water networks, particularly in strategic modernization plans [1, 2]. The calculations were made based on the operational data on the water-pipe network in the town of Krosno, developed based on the failure protocols received from the Municipal Enterprise for Communal Economy in Krosno.

2. Failures of the Krosno Water Network

The main criterion for assessing the state of water pipes is the failure rate index λ_i. Failure rate index estimator per year for particular type of water pipes (mains, distributional and water supply connections), was determined from the formula [1, 3, 4]:

$$\lambda_i = \frac{k_i}{l_i \cdot \Delta t},$$

where: λ_i – failure rate index estimator per year for particular type of water pipes per one year [km^{-1} · a^{-1}],

k_i – number of failures in one year for particular type of water pipes,
l_i – the lenght of particular type of water pipes, on which failures appeared per one year [km],
i – type of water pipes (M – mains, R – distributional, P – water supply connections),
Δt – the lenght of time equal 1 year.

Fig. 3. The scheme of the Krosno water network

Table 1 shows the unit values of the failure rate in the Krosno water-pipe network in the years 2005-2010.

Table 1. The length, number of failures and the failure rate for particular type of water pipes in the years 2005-2010

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Mains						
The length of water pipes	86,8	86,8	86,8	86,8	86,8	86,8
Number of failures	84	101	75	59	46	42
λ_M	0,97	1,16	0,86	0,68	0,53	0,48
Distributional						
The length of water pipes	241,1	242,2	244,6	244,9	245,9	247,8
Number of failures	51	49	40	50	46	44
λ_R	0,21	0,20	0,16	0,20	0,19	0,18
Water supply connections						
The length of water pipes	247,1	249,9	253,1	259,0	264,2	270,1
Number of failures	151	204	119	147	114	141
λ_P	0,61	0,82	0,47	0,57	0,43	0,52

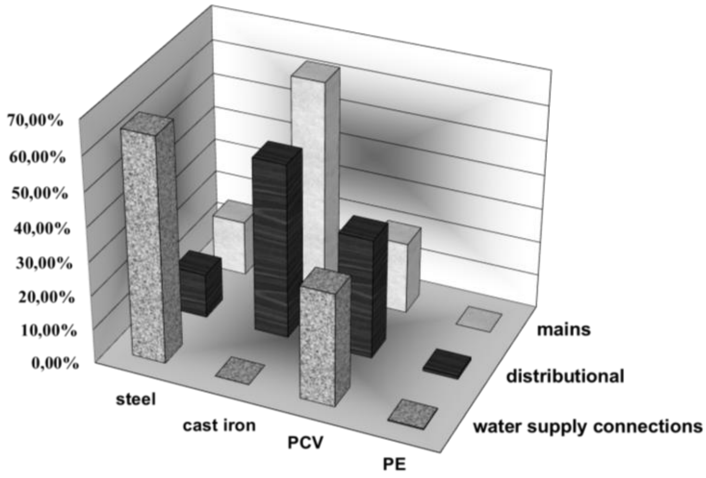
The lowest failure rate have distribution pipelines ($\lambda_{R\acute{s}r}$ = 0,19 km$^{-1}\cdot$ a^{-1}) and the highest failure rate have main pipelines ($\lambda_{M\acute{s}r}$ = 0,78 km$^{-1}\cdot$ a^{-1}). The European criteria say that the pipeline needs repairing when the failure rate index exceeds 0,5 km$^{-1}\cdot$ a^{-1} [5-9].

However, one should seek to the following values of the failure rate index:

- mains $\lambda \leq 0,3$ km$^{-1}\cdot$ a^{-1},
- distributional $\lambda \leq 0,5$ km$^{-1}\cdot$ a^{-1},
- water supply connections $\lambda \leq 1,0$ km$^{-1}\cdot$ a^{-1}.

The calculations show that the distribution pipelines and the water supply connections in Krosno are in good condition, but one should focus on improving the technical state of the main water pipelines. Figure 4 shows the percent of failures in the main water pipes, the distribution pipes and the water supply connections depending on the material from which they were made. 63% of the failures occurring in the main water pipes happened in the cast iron pipes, which results from a significant share of this material in the construction of these pipelines and their significant age. The distribution pipelines are characterized by high failure rate of iron pipes (51% of all failures), and PVC pipes (35%).

Most failures in the water supply connections, as many as 66%, occur in steel pipes, this is due to their poor technical condition. The lower number of failures in pipelines made of PVC and PE is caused by the fact that they are part of the younger sections of water network and that they are resistant to corrosion.



	steel	cast iron	PCV	PE
mains	16,12%	63,00%	20,88%	0
distributional	13,00%	51,12%	34,98%	0,90%
water supply connections	65,62%	0	32,95%	0,29%

Figure 4. The failures in the main water pipes, the distribution pipes and the water supply connections depending on the material from which they were made in 2005-2010

The detailed analysis of the failure rate in water pipes in the years 2005--2010 showed that:

1. Pipes made of PE are characterized by the lowest failure rate. In the water supply connections the failure rate index does not exceed 0,11 $km^{-1} \cdot a^{-1}$ and in the distribution pipelines 0,04 $km^{-1} \cdot a^{-1}$.
2. Iron pipelines in the main pipelines show the highest failure rate. The average failure rate is 1,52 $km^{-1} \cdot a^{-1}$. In the distribution pipelines the average failure rate is 0,36 $km^{-1} \cdot a^{-1}$.
3. The highest failure rate in PVC pipes is seen in the water connections, from 0,7 to 1,27 $km^{-1} \cdot a^{-1}$, and the lowest in the distribution pipelines, from 0,23 to maximum of 0,41 $km^{-1} \cdot a^{-1}$. In the main water pipes the average failure rate was 0,73 $km^{-1} \cdot a^{-1}$.
4. In the steel pipelines the highest failure rate is in the water supply connection, it ranges from 0,76 to over 1,37 $km^{-1} \cdot a^{-1}$, the main pipelines have the average failure rate up to 0,3 $km^{-1} \cdot a^{-1}$. The distribution pipelines have the lowest failure rate, which amounted to 0,09 $km^{-1} \cdot a^{-1}$.

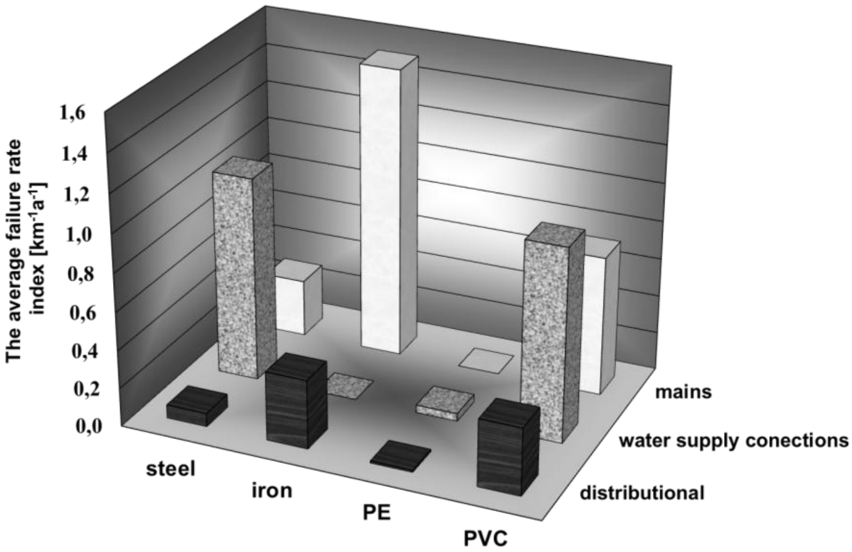
Comparing the determined average failure rate in the water supply system made of different materials with the required values, it is concluded that (Fig. 5):

1. In the case of the main pipelines made of cast iron and PVC the average failure rate is, respectively, 1,52 and 0,73 $km^{-1} \cdot a^{-1}$, while the required value of

failure rate index in the main water network is λ_{Mwym} = 0,3 $km^{-1} \cdot a^{-1}$, the steel pipes, however, have the average failure rate 0,30 $km^{-1} \cdot a^{-1}$.

2. In the case of the distribution pipelines, the average failure rate for pipelines made of steel (0,07 $km^{-1} \cdot a^{-1}$), made of iron (0,36 $km^{-1} \cdot a^{-1}$), made of PE (0,01 $km^{-1} \cdot a^{-1}$) and PVC (0,35 $km^{-1} \cdot a^{-1}$) is lower than the required value λ_{Rwym} = 0,5 $km^{-1} \cdot a^{-1}$.

3. In case of the water supply connections, the average failure rate in steel pipelines and PVC pipelines (values respectively 1,07 and 1,01 $km^{-1} \cdot a^{-1-}$) is higher than the required value λ_{Pwym} = 1,0 $km^{-1} \cdot a^{-1}$.



	steel	iron	PE	PVC
□ mains	0,3	1,52	0	0,73
▨ water supply conections	1,07	0	0,04	1,01
■ distributional	0,07	0,36	0,01	0,35

Fig. 5. The average failure rate index for particular type of water pipes in the years 2005-2010

Table 2 shows the percentage of failures depending on the diameter and material of water pipes in the years 2005-2010. It is clearly visible that the most often the failures occur in the water connections with a diameter of 32 mm, made of steel (14,5% of all failures). The next frequent are the failures in pipes made of PVC and steel, with a diameter of 40 mm, respectively 12% and 9,6% of all failures.

Table 2. The percentage of failures depending on the diameter and material of water pipes in the years 2005-2010

Diameter [mm]	Steel	Iron	PVC	PE
25	2,7%	-	0,24%	0,00%
32	14,5%	-	0,47%	0,08%
40	9,6%	-	12,00%	0,39%
50	8,8%	-	4,18%	0,00%
63	0,6%	-	1,34%	0,32%
80	1,8%	4,74%	3,00%	0,16%
100	0,5%	4,26%	3,16%	-
150	2,0%	3,47%	4,03%	-
200	0,2%	0,39%	0,47%	-
250	0,2%	4,42%	0,00%	-
300	0,0%	2,68%	0,00%	-
350	0,0%	2,05%	0,00%	-
400	0,0%	3,63%	0,00%	-
500	1,1%	2,53%	0,00%	-

3. Conclusion

Based on the analysis of the results of the studies, the following conclusions and statements were made:

- the average failure rate for the main pipelines is $\lambda_{M\acute{s}r}$ = 0,74 $km^{-1} \cdot a^{-1}$, the distribution pipelines $\lambda_{R\acute{s}r}$ = 0,19 $km^{-1} \cdot a^{-1}$ and the water connections – $\lambda_{P\acute{s}r}$ = 0,56 $km^{-1} \cdot a^{-1}$,
- the majority of failures (55,22%) happen in the water connections (25 to 63 mm diameter), representing about 44% of the total length of the pipelines,
- the lowest failure rate is in the distribution pipelines made of PE – $\lambda_{PE\acute{s}r}$ = 0,01 $km^{-1} \cdot a^{-1}$, which results from their use since the 1990s,
- for the water connections made of steel the average failure rate is $\lambda_{stal\acute{s}r}$ = = 1,07 $km^{-1} \cdot a^{-1}$, the highest average failure rate is found in the cast iron main water pipelines $\lambda_{\dot{z}eliwo\acute{s}r}$ = 1,52 $km^{-1} \cdot a^{-1}$, which is caused by the fact that steel and iron are the oldest materials used to build that water supply network,
- the value of failure rate indexes corresponds to national trends [2, 10-15], the declining trend in both the number of failures and failure rate in water pipelines is seen.

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ANALIZA AWARYJNOŚCI SIECI WODOCIĄGOWEJ KROSNA

Streszczenie

W pracy przedstawiono analizę awaryjności sieci wodociągowej Krosna. Zakres pracy obejmuje analizę wskaźników intensywności uszkodzeń przewodów magistralnych, rozdzielczych oraz przyłączy wodociągowych na przykładzie sieci wodociągowej Krosna. Analizę przeprowadzono na podstawie danych eksploatacyjnych sieci wodociągowej w latach 2005-2009, uzyskanych od MPGiK w Krośnie. Dokonano analizy awaryjności ze względu na zastosowany materiał, wiek oraz średnicę dla poszczególnych rodzajów przewodów wodociągowych.