ACCEPTANCE CRITERIA FOR RISK ASSESSMENT IN WATER SUPPLY SYSTEM IN TERMS OF FAILURE PREDICTION

TCHORZEWSKA-CIESLAK B.[1] and PIETRUCHA-URBANIK K.[2]

[1] Department of Water Supply and Sewage Systems, Rzeszow University of Technology, 35-950 Rzeszow, Al. Powstańców Warszawy 6, Poland Barbara Tchórzewska-Cieślak,
[2] Department of Water Supply and Sewage Systems, Rzeszow University of Technology 35-950 Rzeszow, Al.Powstańców Warszawy 6, Poland, Katarzyna Pietrucha-Urbanik
E-mail: kpiet@prz.edu.pl

ABSTRACT

The paper presents the problem of network failure risk assessment in water supply system. Problems of water supply network failure are based on previous studies carried out in different research centres. Attention has been paid to the problem of risk assessment in the context of risk acceptance criteria values. Different concepts approach to risk assessment were presented, taking into account the normative adopted for other technical systems. In the work, based on analysis, criteria values were proposed for assessing the risk of water supply network failure. An example of criteria application was used for the exemplary water supply network.

The obtained information describing the general characteristics of the examined system, and the technical conditions of the water supply system, the relationship between the type of network in terms of function, pipe diameter or material and the failure intensity can be used in the assessment of failure prediction of the water supply network.

Keywords: water supply system, failure risk criteria, failure prediction

1. Introduction

1.1. Review of existing state of knowledge

With the functioning of water supply system (WSS), we have contact every day, as being consumers of drinking water. There are many studies in terms of reliability and safety []. In the work (Wieczysty, 1990) the basic operating conditions of WSS, depending, among others, on the degree of coverage of the total water demand, were defined. The division of water consumers into five categories was established in (Kwietniewski *et al.*, 1993), which takes into account the required quantity of water supply Q_w compared to the total nominal water demand Q_n. The solution presented in (Twort, 2000) takes into account the technical and social aspects of the required level of reliability of the system and subsystems of rural water supply, as defined by the minimum failure rate obtained on the basis of operational data.
The indicators of reliability in terms of physico-chemical quality of drinking water and the concept of tolerable risk of exceeding the quality standards for drinking water (W) were introduced in the thesis (Rak, 2009). Water supply system has its own characteristics and its various subsystems perform different functions, while interacting with each other form an integral whole (ISO 24512:2007).

The aim of this paper is to propose a new scheme for operational assessment related to technical functioning of the system on the example of examined WSS .

2. Methodology

2.1. Theoretical basis of the failure risk analysis and assessment of the water supply system

Risk (r) can be presented as a function of availability indicator ($r = R(t)$), where availability indicator expresses the similarity in which the object will be in operational capability at the time t and it is determined as the dependence of the average operating time between failures Mean Time

Between Failures *MTBF* per sum of the *MTBF* and the Mean Time to Repair MTTR (Kołowrocki and Soszyńska-Budny, 2011). The risk is regarded in context of safety in face of hazardous situation resulting in threat for water recipients (IEC 61508-4; IEV 191-12-07).

The failure rates used in the functioning analysis of the water supply system are:

- the failure rate $\lambda(t)$ [number of failures·year (day)$^{-1}$] or [number of failures·km^{-1}a^{-1}]. This indicator is used in the analysis and assessment of the water supply system failure and calculated as the average value of the damage intensity of pipes, connectors and fittings. It is calculated as the total number of failures in the time interval by the number of analysed elements or for linear elements their length L [km] and time of observation,
- Mean Time Between Failures MTBF [d], which is the expected value defining operating time (ability of the system (or its components) between two consecutive failures,
- Mean Time To Repair MTTR [h] describes the value of time from the moment of failure until re-enable water flow on the damaged section of the water supply network,
- the repair rate $\mu(t)$ [number of repairs·a(h)$^{-1}$] determines the number of failures repaired per time unit, it can be determined as the reverse of the mean repair time.

2.2. Material

The history of the examined water supply dates back to the mid-seventies of the twentieth century. Water supply network is developed in the whole territory of the municipality and about 95% of the total population benefit from water supply system, the rest of the population uses water from their own household wells.

Water for the residents of the municipality is derived from six intakes (drilled wells located in the municipality), the commune has three water treatment plants, additionally there is an emergency intake with a distinct water treatment station. Water supply system is composed of: the main section of the distribution network of 1500 m (∅500), 3 rings of the distributional network and straight sections of the distribution network, and a separate distribution network for one of the intakes and the numerous water supply connection.

Material composition of the examined water supply network is not diverse, approximately 2% of the network are steel pipes, PVC pipes are also about 2% of the total length of the water supply system, and the rest of the pipes are made of PE, which is currently the only material used in construction of the water pipes. There are also about 800 meters of asbestos water pipes, but after numerous failures and constant interruptions in the supply of water to the residents of the local area, asbestos is being slowly replaced by polyethylene.

3. Results

The percentage distribution of the failure number depending on its types in 7-years period of observation were shown on the Figures 1-4. The detailed analysis has shown that in the case of water supply network fittings the biggest impact on the number of failures have unsealing and leaks - 55%, corrosion and freezing represent the 33% of the total failure of the water supply system fittings, cracking and mechanical damage only 12%. The largest number of water supply connections failures was caused by cracks, which are constituted 55% of the total damages, the smallest number of failures occurred in case of corrosion, while freezing represent 17%, mechanical damage about 13%.

The analysis of the failure rate, which constitutes the base of acceptance criteria for risk assessment in water supply system indicates: the average failure rate for the distributional pipe is λ_{davg} = 0.17 [(number of failures)/(year·km)], for the water connections λ_{wcavg} = 0.236 [(number of failures)/(year·km)], while for the water network fittings λ_{favg} = 10.8 [(number of failures)/year]. In the case of the distribution network, it can be observed that the values of the failure rate are almost at the same level and range from 0.13 to 0.19 [(number of failures)/(year·km)]. Analyzing the values of the failure rates of the water supply connections, it can be seen that these values tend to rise while in the case of water network fittings the opposite trend is observed, the failure rate decreased to 13 [(number of failures)/year].

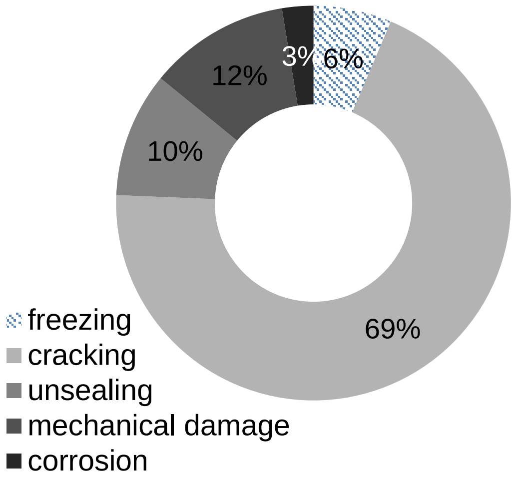

Figure 1: The percentage distribution of failures types of the distributional pipe.

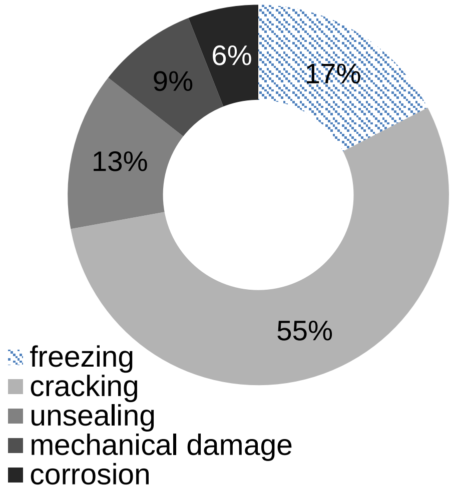

Figure 2: The percentage distribution of failures types of the water connections.

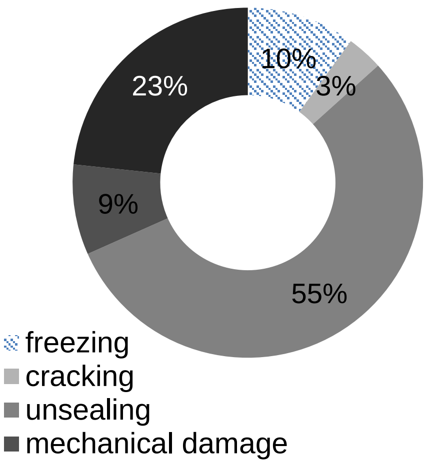

Figure 3: The percentage distribution of failures types of the water supply system fittings.

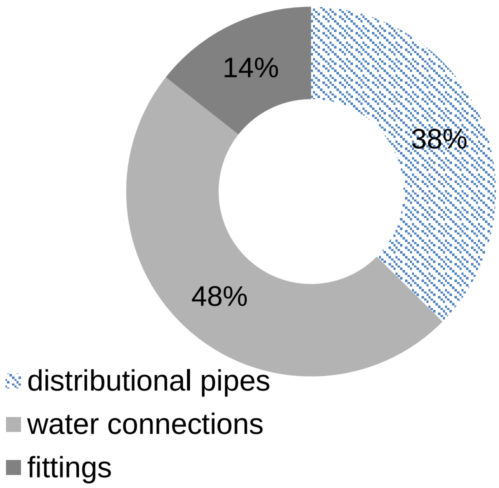

Figure 4: The percentage distribution of failures types of the water supply system.

In order to determine what kind of failure has the great impact on the failure rate in Table 1 the number of failures depending on the cause and the failure rate were presented.

Table 1: Summary of the failure rates for different failures and water network type.

Failure type	Freezing	Cracking	Unsealing	Mechanical damage	Corrosion
Distributional					
λ_{davg} [(number of failures)/(year·km)]	0.009	0.125	0.015	0.018	0.005
Water connections					
λ_{wcavg} [(number of failures)/ (year·km)]	0.039	0.131	0.033	0.020	0.015
Water supply fittings					
λ_{favg} [(number of failures)/year]	1.2	0.4	6.6	1	2.8

The mean operating time between failures occurring in the water network is for the distributional pipe $MTBF_d$ = 7.76 d, for the water connections $MTBF_{wc}$ = 7.5 d and for water pipe fittings $MTBF_f$ = 18.07 d. These results illustrate how often different types of failure occur in the water network. In the case of the distribution network the repair time depends on the pipe diameter on which the failure occurs, such diameters are larger than the water supply connections diameters, what usually causes the use of heavy equipment. The number of distributional failures lasting more than one working day is less than in the case of water supply connections, usually MTTR equals 8 h and the repair rate μ = 0.125 1/h.

4. Acceptance criteria for risk assessment in water supply system

The precise definition of operating states of WSS has a significant impact on the analysis of reliability and safety of the system. A new scheme is proposed in this field, which defines the following operating conditions in water supply system, Table 2.

Table 2: The required values of reliability indicator depending on the water supply category

Category of water supply system		Water network supplying less than 2000 recipients	Water network supplying settlement units of more than 2000 and less than 200 000 recipients	Large water network supplying more than 200 000 recipients	Particularly important industrial plants, hospitals
Acceptation criteria					
λ(t) [number of failures·k $m^{-1}a^{-1}$]	tolerable	≤ 0.9	≤ 0.5	≤ 0.5	Determined on the basis of a detailed analysis
	controlled	from 0.9 to 2.0	from 0.5 to 1.5	from 0.5 to 1.0	
	unacceptable	≥ 2.0	≥ 1.5	≥ 1.0	
MTTR [h]	tolerable	≤ 3	≤ 2	≤ 2	
	controlled	from 3 to 24	from 2 to 18	from 2 to 12	
	unacceptable	≥ 24	≥ 18	≥ 12	
R(t)	tolerable	≥ 0.9917808	≥ 0.9945205	≥ 0.9986301	
	controlled	≥ 0.9863014	≥ 0.9917808	≥ 0.9972603	
	unacceptable	≥ 0.9726027	≥ 0.9835616	≥ 0.9945205	

The average availability indicator R(t) for the distributional pipe equals 0.95881384, for the water connections R(t) = 0.95744681 and for the water network fittings R(t) = 0.95881384, each of these values is smaller than the criteria proposed in Table 2 (for the water network supplying less than 2000 recipients).

5. Conclusion and perspectives

For the risk assessment, the indicators of the frequency of the probability of occurrence of undesirable events and the indicators related to the time duration of the individual operating states, should be used.

Water supply system is characterized by a continuous operation, its reliable and safe operation has a direct impact on the quality of life of water consumers.

Failures in WSS do not occur without a cause, often occur in a chain of undesirable events, there are also a result of making wrong decisions and poor management, resulting in a negative impact on the operation of WSS.

Risk and failure analyses in WSS should be standard in its operation.

Presented issue is intended to draw attention to the need for further improvement and standardization of criteria related to analysis and risk assessment in WSS.

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