Principle of Equireliability at the Internal Water-Supply System Design

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Abstract The question of reliability increase in construction at the internal engineering networks designing is analyzed. The influence of the houses connection place to the water-supply system from the reliability point of view is established. The acceptance of the basic reliability indicators for calculating the continuity and renewability of water-supply is substantiated. The main indicators of the water-supply systems reliability in the selected direction should be taken as the mean failure time T and the mean recovery time T_R, and the complex indicator—the water-supply system readiness ratio for the direction K_R was set. Mathematical model for calculating the reliability of interior water-supply systems is a consistent combination of renewable elements. It includes a raising pumping station and a water-supply network. The choice of the place of house internal water-supply network connection in the center of equireliability is substantiated, and the calculations of the basic reliability indicators are made. With the optimum connection of the house to the external water-supply network, the faultlessness of the internal network in the least reliability direction was increased by 29%.

Keywords Reliability · The center of equireliability · Inlet of water-supply pipeline to the house

1 Introduction

The water-supply system is a chain of serially connected individual units (structures) from the water source to the consumer. It is necessary to maintain the reliability of all links in this chain for the reliable functioning of the water-supply path. One of these links is the in-house water-supply network—the last link on the water way into the apartment. "The rules for the provision of services to the public for district heating, hot and cold water-supply and sewerage" [1] require that "the permissible period of

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deviation from uninterrupted water-supply is no more than 6 h per day and no more than two times per month." To ensure regular and renewable water-supply at this last link in the system, it is possible to increase the faultlessness and repairability, both through the use of new technological means and the use of reasonable technical solutions.

2 Problem Statement

Analysis of recent researches [2–11] shows that both scientists and water professionals are paying attention to solving the problem of water-supply reliability. However, when justifying the choice of water source location in an external water-supply network, usually only technological and economic factors are taken into account and reliability issues are not taken into account. For any building, including a residential unit, the water source for the internal water-supply network should be considered as the node (point) of connection to the external network, and then, the connection location should be chosen based on reliability.

3 The Aim of Research

The choice of the place of house internal water-supply network connection in the center of equireliability is substantiated, and the calculations of the basic reliability indicators are made and to carry out practical calculations of the basic reliability indicators.

4 Improving the Houses Water-Supply Reliability by Choosing a Connection to the Water-Supply System

4.1 Problem Formulation

One of the main issues during the design phase of internal water-supply systems is the choice of the building's connection location to an external water-supply system. Considering reliability, the main factors that influence the choice of the building's connection place to the water-supply system are the purpose of the water-supply system, the type, and length of the networks. If the internal water-supply system of a residential building with a conventional height of up to 26.5 m is designed or reconstructed, such water-supply system does not perform fire-fighting functions and has a branched-type water-supply network [12]. In such case, the main reliability indicators should be **the mean failure time** T and **the mean recovery time** T_R, and

the complex indicator—**the readiness ratio K_R for the direction** of water-supply. This direction is determined from the input node to the dictating consumer, but the location of the input, relative to the dictating consumers, affects the reliability of the water-supply to them. This is due to the fact that the faultlessness of the supply pipeline is influenced by two main factors: the diameter and length of the pipeline (with the selected pipe material). The greater the length of the feed pipeline, with the accepted diameter and material of the pipes, the less the failure time T is. The optimum condition of reliability is the location of the internal water-supply system inlet, when the operating failure time T from the point of water-supply input to all dictating consumers is maximally possible, and the parameters of failure flow ω to dictating consumers are minimally possible. If the distances from the input node to the dictating consumers are the same, then we get the scheme of equal reliability, that is, the principle of water-supply equireliability to consumers is maintained. The optimization criterion should be the parameter of water-supply system failure's flow in the direction of water-supply from the inlet to the dictating consumer is equal $\omega = \frac{1}{T}$.

4.2 The Center of Equireliability

From reliability point view of, a building's connection is optimal, when the reliability of water-supply to all consumers will be maximally possible [13]. Let us call this point of the network as the center of equireliability. In terms of reliability theory, this means that failure time to dictate consumers should be maximized. It is more convenient to perform calculations through the failure flow parameters of the direction $\omega_d = \frac{1}{T}$. Most often there will be a situation where the equireliability center is located on a section of water-supply network between two nodes. If at this point it is not possible to form an input node, the equireliability center must be moved to the nearest node of the internal water-supply network.

4.3 Mathematical Justification for the Equireliability Center Search

Branched-type water-supply networks are networks without cycles that can be displayed as trees with a root at the top where the water source is located, and therefore, there is a path between any two vertices and, moreover, only one. In internal water-supply systems, the water source is an input node for connection to external networks. In [13], the mathematical justification of the equireliability center search for external branched-type networks was performed. It is proved that the equireliability center is located in the middle of the largest chain, which consists of series-connected sections of the external network. Vertical raisers, which are connected in the building's basement by the main road, also represent a branched-type water-supply network (Fig. 1).
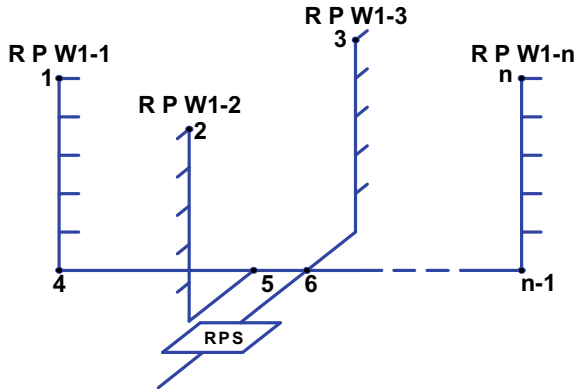
Fig. 1 Scheme of an internal water-supply system of a five-story building

Obviously, the longest chain will be a chain of sequentially connected sections 1–4–5–6–$(n - 1) - n$ from node 1 to node n. Next, you need to find the middle of this chain and at this point place the input node and raiser pumping station (RPS). For algorithmically solving the problem, we use an algorithm with the transition to the parameter of the failure flow. First, we find the sum of the failure flow parameters from the first node of the vertex to all others, then from the second—to all others. In the following iterations, we find the values of the failure flow parameters between all the end nodes. In modern water-supply systems, the water pressure in external networks is reduced to 0.1 MPa to reduce water leakage and pipes damage, and in individual residential houses or groups of buildings, RPS is installed. The following example is considered below.

4.4 Mathematical Model of Internal Water-Supply System with RPS Reliability

The elements of the water-supply system will be RPS and network sections of different diameters. We will assume that the pipes and fittings of the network have the same reliability, given the slight difference in diameters. For reliability calculations, we use the following dependencies.

Failure flow parameter for the ith section of the network.

$$\omega_{s_i} = \sum_{i=1}^{n} \omega_{0_i} L_i, \tag{1}$$

where

L_i length of the pipeline section of the ith diameter, km;
ω_{0_i} failure flow parameter of ith diameter of 1 km pipeline

Network failure flow parameter in the selected direction

$$\omega_n = \sum_{i=1}^{n} \omega_{s_i},\tag{2}$$

where

n the number of network sections in the selected direction

Raiser pump station failure flow parameter [14]

$$\omega_{ps} = \sum_{i=1}^{N} \upsilon_i,\tag{3}$$

where

υ_i contribution of the ith enlarged element to the raiser pump station failure parameter;
N the number of enlarged items

Failure flow parameter of the water-supply system in the selected direction

$$\omega_d = \omega_{ps} + \sum_{i=1}^{n} \omega_{0_i} \cdot L_i.\tag{4}$$

Mean failure time of the system in the selected direction

$$T = 1 \Big/ \left(\omega_{ps} + \sum_{i=1}^{n} \omega_{0_i} \cdot L_i\right).\tag{5}$$

Mean system recovery time in the selected direction

$$T_R = \left(T_R^{ps}\omega_{ps} + T_R^n\omega_n\right) / \left(\omega_{ps} + \omega_n\right),\tag{6}$$

where

T_R^{ps} the mean recovery time of the pumping station;
T_R^n mean time of network recovery in the direction

Mean network recovery time for the selected direction

$$T_R^n = \left(\sum_{i=1}^{n} T_{R_i}^s \omega_{s_i}\right) \Big/ \sum_{i=1}^{n} \omega_{s_i},\tag{7}$$

where

$T_{R_i}^s$ the mean recovery time of the ith network section

Readiness coefficient of the water-supply system in the selected direction

$$K_R = T/(T + T_R). \tag{8}$$

5   Calculation of Water-Supply Reliability

Let us consider, for example, the five-story building with PNS. There are 130 consumers and 300 water dismantling devices installed, pipe material—polypropylene. According to the principle of equireliability, optimal location of water-supply input to the house will be a connection closer to the middle of the house, and not from the end of the house (Fig. 2). Hydraulic calculation for two variants of the house connection was carried out, and diameters of water pipes and distribution network were adopted. The calculations were made in tabular form (Table 1). The most distant from the input of the house water-supply system and the high-mounted water disassembly device was adopted by the dictating consumer.

The calculation of the RPS reliability was performed by the contribution method [2] for two pumping units [14]—working and reserve (Fig. 3).

$$\omega_1 = 2\omega_{_{3\theta}} = 2 \times 0.1 \times 10^{-4} = 0.2 \times 10^{-4} \, 1/h;.$$

$$\omega_2 = \omega_3 = \omega_p + \omega_v = (1.25 + 0.08) \times 10^{-4} = 1.33 \times 10^{-4} \, 1/h;$$

$$\omega_4 = 2\omega_{dv} = 2 \times 0.6 \times 10^{-4} = 1.2 \times 10^{-4} \, 1/h.$$

$$T_{R_1} = T_{R_{dv}} = 20 \, h;$$

$$T_{R_2} = T_{R_3} = \frac{\omega_p T_{R_p} + \omega_v T_{R_v}}{\omega_p + \omega_v}$$

$$= \frac{(1.25 \times 60 + 0.08 \times 10) \times 10^{-4}}{(1.25 + 0.08) \times 10^{-4}} = 56.99 \, h;$$

$$T_{R_4} = T_{R_{dv}} = 10 \, h.$$

$$K_{D_3} = \omega_3 T_{R_3} = 1.33 \times 10^{-4} \times 56.99 = 75.8 \times 10^{-4}.$$

$$\upsilon_1 = \omega_1 = 0.2 \times 10^{-4} \, 1/h;$$

$$\upsilon_2 = \omega_2 K_{D_3} = 1.33 \times 10^{-4} \times 75.8 \times 10^{-4} = 10^{-6} \, 1/h;$$

$$\upsilon_4 = \omega_4 = 1.2 \times 10^{-4} \, 1/h.$$

$$\omega_{ps} = \upsilon_1 + \upsilon_2 + \upsilon_4 = (0.2 + 0.01 + 1.2) \times 10^{-4}$$
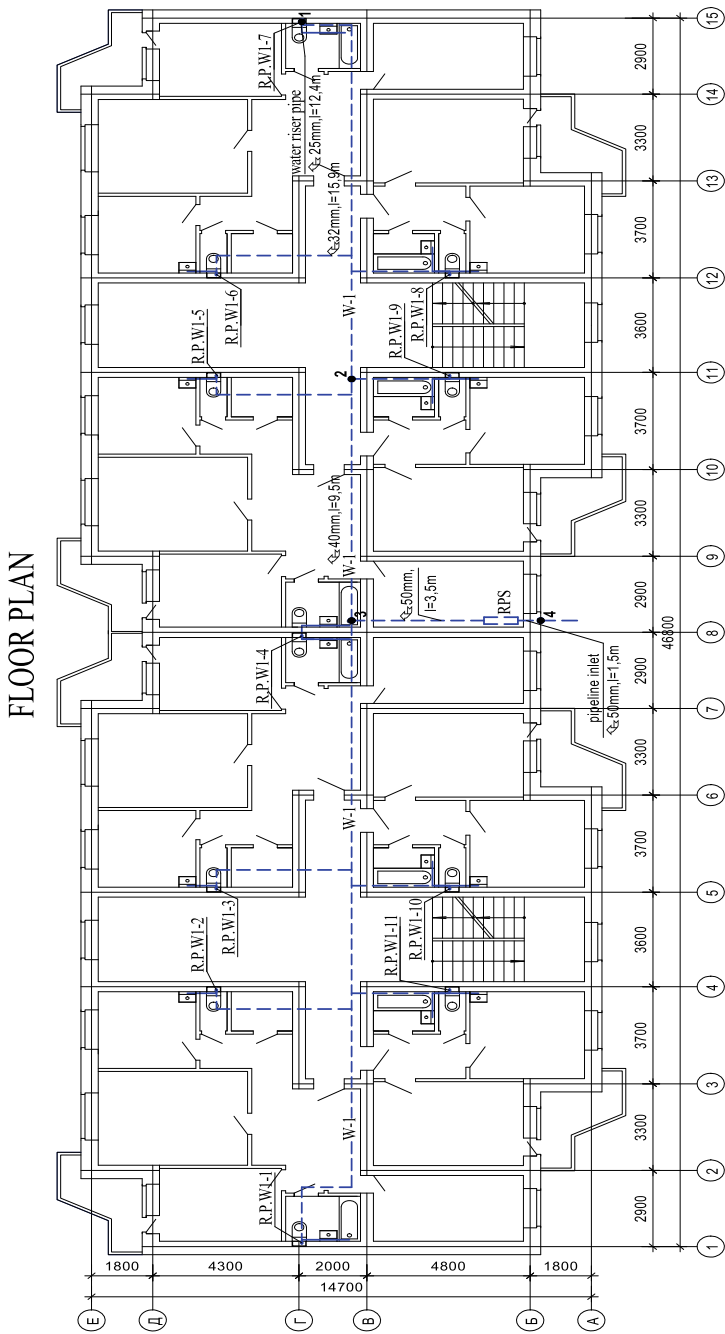
$$= 1.41 \times 10^{-4} \, 1/h.$$

FLOOR PLAN

Fig. 2 Network plan for water-supply entering in the middle of the house. *Legend* Rp B1-1—water raiser pipe №1; RPS—raiser pumping station

Table 1 Reliability calculation of the house water-supply system

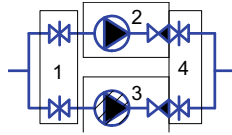| Internal pipeline sections	Diameters of pipes D (mm)	Lengths of sections L (km)	Failure flow parameter, 1/h				System failure time by the direction, T Hours/days	Recovery time T_R, (h)	Readiness coefficient K_R
			Network by direction ω_n	RPS Ω_{ps}	Network with fitting by direction ω_s	System by the direction ω_s			
Variant 1 (water input from the end of the house)									
3–4	50	0.0025	2.76×10^{-6}	141×10^{-6}	5.54×10^{-6}	146.54×10^{-6}	6825/284	11.5	0.998318
2–3	40	0.0299							
1–2	32	0.0159							
Raiser pipe	25	0.0124							
Variant 2 (water input in the middle of the house)									
3–4	50	0.005	1.95×10^{-6}	141×10^{-6}	3.90×10^{-6}	144.9×10^{-6}	6901/288	11.6	0.998322
2–3	40	0.0095							
1–2	32	0.0159							
Raiser pipe	25	0.0124							

Fig. 3 Scheme of the pumping units

$$T_{PS} = \frac{1}{\omega_{ps}} = \frac{1}{1.41 \times 10^{-4}} = 7092.2\,\text{h}.$$

$$T_{R_{ps}} = \frac{\upsilon_1 T_{R_1} + \upsilon_2 T_{R_2} + \upsilon_4 T_{R_4}}{\omega_{ps}}$$

$$= \frac{(0. \times 20 + 0.01 \times 56.99 + 1.2 \times 10) \times 10^{-4}}{1.41 \times 10^{-4}} = 11.75\,\text{h}.$$

6   Conclusion

1. With optimal house connection to the external water-supply network, the network faultlessness in the direction of the least reliability was increased by 29%
2. The raiser pumping station significantly reduces the reliability of water-supply. Its failure rate is two values more than the network.

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