Calibration of the water distribution network model

T. Koppel¹, N. Kändler¹ & A. Vassiljev²
¹Department of Mechanics,
²Department of Environmental Engineering,
Tallinn Technical University, Estonia

Abstract

As a rule models for water distribution systems have to be calibrated for better reflection of the behaviour of the real system. As the first step of calibration the distribution of water losses due to leakage must be studied. Two approaches are proposed in order to calculate the leakage from pipes. The first of them uses an empirical formula which takes into account the length of pipe and mean pressure. This leakage is carried to the terminal nodes and distributed between the nodes proportionally to the pressure in the nodes. For evaluation of pressure in the nodes an iteration process is applied which determines the leakage and pressures intermittently. The second approach uses differences between the measured and calculated pressures. Areas with underestimated and overestimated pressure have been selected and coefficients for the correction of the leakage for these areas calculated. Calculated results for the water distribution network of the City Centre of Tallinn are presented, demonstrating the applicability of the above methods.

1 Introduction

In the course of calibration of the simulation model of water network the main parameters which can be modified during the adjustment phase are uncontrolled consumptions and pipe roughnesses. Several methods are proposed for the calibration of network models. The unaccounted water problem is considered by Andrés and Planells [1], Martínez and Garcia-Serra [2], Vela et al. [3], Germanopoulos [4], and Tucciarelly et al. [5]. The calibration problem with regard to pipe roughness values is dealt by Germanopoulos [4], Ormsbee and
Lingireddy [6], and Greco and Del Giudice [7]. The acceptable accuracy of calibration must correspond to the available input data. Moreover, we must take into consideration that there are multiple combinations of pipe roughness values that produce the same head loss across the network. This task is complicated if the network consists of pipes of different age. The uncontrolled consumptions are due to leaks, illegal connections, meter errors, etc. It is very difficult to estimate these volumes and their spatial and time distribution. Only the total volume of uncontrolled consumptions can be determined evaluating the difference between the volume of total input and the volume of registered water. If this difference is around 10 - 15\%, the traditional method, which adopts proportionality between the controlled and uncontrolled flow rates in the nodes, can be used (Martinez and Garcia-Serra [2]). If the difference is bigger, the unproportionality in the distribution of uncontrolled consumptions must be taken into account. Since it is difficult to determine the components of uncontrolled consumption, the whole uncontrolled flow is usually treated as leakage. Some methods are proposed for evaluation of the distribution of leaks in the network. Vela et al. [3] proposed to simulate a leak with a fictitious discharge valve for this purpose and to determine the number of defects by statistical criteria and historical data. Germanopoulos [4] gives a formula for determination of leakage losses from the network. In Ainola et al. [8] this formula, which takes into account the length of pipe and mean pressure in it, is generalised and used. The leakage is carried to the terminal nodes and distributed between the nodes proportionally to the pressure in the nodes. Initially the pressure in the network is unknown. It depends on the water demand and leakage. Therefore an iteration process is applied which determines the leakage and pressure intermittently. In this paper this method is compared to another method of distribution of the leakages which is based on taking into consideration the differences between the measured and calculated pressures at the control nodes.

2 Distribution of leakage on the basis of pipe length and pressure in the nodes

Let us generalise the formulas for determination of leakage losses given by Germanopoulos [4] and Tucciarelly et al. [5] and write

\[ S_{ij} = c \alpha_{ij} L_{ij} \left( \frac{p_{ij}}{\bar{p}_{ij}} \right)^b, \]

where \( S_{ij} \) is the leakage outflow from the pipe connecting nodes \( i \) and \( j \), \( c \) is the leakage coefficient of proportionality for the whole network, or for pressure zone, \( \alpha_{ij} \) is the coefficient, which is a function of pipe diameter, age and its material, and it takes into account the areas where the pipe lies, \( L_{ij} \) is the pipe length, \( p_{ij} \) is the average pressure along the pipe, and \( b \) is an exponent of pressure. The average pressure along the pipe can be approximated as
where $p_i, p_j$ are pressure in the nodes $i$ and $j$ respectively. Now we can write

$$S_{ij} = (0.5)^b c \alpha_{ij} L_{ij} (p_i + p_j)^b.$$  \hspace{1cm} (3)

If we distribute the leakage of pipe between the terminal nodes we can write

$$S_{ij} = Q_{ij} + Q_{ji},$$  \hspace{1cm} (4)

where $Q_{ij}$ is the leakage from node $i$ caused by the pipe which connects this node with node $j$, and $Q_{ji}$ is leakage from node $j$, caused by the pipe which connects this node with node $i$. Let us assume that the leakage from the pipe is distributed between the terminal nodes proportionally to the pressure in the nodes. Then we have

$$Q_{ij} = (0.5)^b c \alpha_{ij} L_{ij} p_i (p_i + p_j)^{b-1},$$  \hspace{1cm} (5)

$$Q_{ji} = (0.5)^b c \alpha_{ij} L_{ij} p_j (p_i + p_j)^{b-1}.$$

The total volume of leakage from node $i$ is equal to

$$Q_i = cQ_i^*,$$

where

$$Q_i^* = \sum_{j=1}^{N_i} (0.5)^b \alpha_{ij} L_{ij} p_i (p_i + p_j)^{b-1}.$$  \hspace{1cm} (6)

Here $N_i$ is the total number of pipes linked to node $i$. The leakage coefficient of proportionality $c$ is determined as

$$c = \frac{k}{M} \frac{1}{\sum_{i=1}^{M} Q_i^*},$$  \hspace{1cm} (7)

where $k$ is the total volume of leakage and $M$ is the total number of nodes in the network. Initially we do not know the pressure in the network. It depends on the water demand and leakage. Therefore, an iteration process for determination of pressure must be applied. Thus, proceeding from the pressure in nodes which are calculated for proportionally distributed leakage, the pressures and leakages can intermittently be determined.
3 Distribution of the uncontrolled consumptions on the basis of differences between measured and calculated pressures

We proceed from the calculation with the assumption that leakages are distributed proportionally to the controlled flow rates. To improve this distribution let us take into account the differences between the measured and calculated pressures in the control nodes. For that reason the network has been portioned into regions and for each region the arithmetical mean of the measured and calculated pressures $p_i^*$ and $p_i$ ($i = 1, 2, ..., n$) has been found. We assume that the head loss $H$, associated with flow $Q$, can be expressed as

$$H = aQ^2,$$

where $a$ is the resistance coefficient. Let us find the differences in flow $\Delta Q_{ik} = \alpha_i Q_{ik}$ at all nodes $k$ in the region $i$ that correspond to the mean differences of pressure. We obtain

$$H_i + p_i^* - p_i = a(1 + \alpha_i)^2 Q_{ik}^2.$$

From this follows

$$\alpha_i = \sqrt{1 + \frac{p_i^* - p_i}{H_i}} - 1.$$ (9)

Further, using coefficients $\alpha_i$ we redistribute the flows in regions taking

$$Q_{ik}^* = c^*(1 + \alpha_i)Q_{ik},$$

where $c^*$ is the coefficient of proportionality, which is determined as

$$c^* = \frac{\sum_{i=1}^{n} \sum_{k=1}^{N_i} Q_{ik}}{\sum_{i=1}^{n} (1 + \alpha_i) \sum_{k=1}^{N_i} Q_{ik}},$$

where $N_i$ is the number of nodes in region $i$. Both methods of the distribution of leakages were used for the water distribution system model of the City Centre of Tallinn.

4 Leakage distribution in network model of the City Centre of Tallinn

At present the number of inhabitants in Tallinn is approximately 450 000 and water consumption equals to 100 000 m$^3$/day. The water network of Tallinn can be divided into several pressure zones. The main reason here is not the substantial difference in ground level, but the length of pipelines. The algorithm for the distribution of leakage has been used for the network of the City Centre
of Tallinn. This is the most complicated part of the network, where some pipes date back to the year 1883. Unaccounted for water is here equal to 28%. Modelling of the network has been done on the basis of the EPANET software. The EPANET has excellent possibilities for the integration of different programs. You can run a lot of EPANET functions directly from your software. We have used the given approaches to distribute leakages. Each of them was compared to a model in which leakages were distributed proportionally to consumption. Figure 1 shows the differences between the calculated and measured pressures for the initial version with the distribution of leakages proportionally to consumption.

Figure 1: Differences between measured and calculated pressures (black means that the difference between calculated - measured is negative, grey means that the difference is positive).
In order to redistribute the leakages by the first method we have used the iteration process. Figure 2 shows the convergence of the leakage coefficient of proportionality $c$ during such an iteration process. Figure 3 shows the differences between the calculated and measured pressures for this approach. The standard deviations for the method are given in Table 1.

![Convergence of the leakage coefficient of proportionality during iteration process](image)

**Figure 2:** Convergence of the leakage coefficient of proportionality during iteration process

The second approach allows us to distribute leakages on the basin of comparison of calculated and measured data. One can see on Figure 1 that there are areas where the differences between the calculated and measured pressures are positive and there are areas with negative differences between them. Supposing that negative differences belong to the areas where leakages are overestimated and positive differences belong to the areas with leakages underestimated, we have divided the whole area into 5 regions and redistribute leakages according to the second method. Figure 4 shows the differences between the calculated and measured pressures in this case. One can see the great changes for the nodes in the upper left corner of the network. The differences between the calculated and measured pressures were mostly negative before the redistribution of leakages (Figure 1) and after redistribution (Figure 4) the negative values have decreased and the positive values have appeared in this area. The standard deviations of the differences between calculated and measured pressures for both methods of leakage distribution are given in Table 1 and the results show that standard deviation decreased significantly in the second case of leakage redistribution.
Figure 3: Differences between measured and calculated pressures (leakages distributed proportionally to the pressures)

Table 1. Standard deviations of the differences between calculated and measured pressures

<table>
<thead>
<tr>
<th>Leakages distributed proportionally to consumption</th>
<th>Leakages distributed proportionally to pressure</th>
<th>Leakages distributed proportionally to the differences of pressure</th>
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<tr>
<td>1.79</td>
<td>1.76</td>
<td>1.68</td>
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Figure 4: Differences between measured and calculated pressures (leakages distributed proportionally to the differences of pressure)

5 Conclusions

Two models of leakage distribution are proposed. The application of the methods for the water network model of the City Centre of Tallinn brought about a certain decrease of the differences between the measured and calculated pressures. The bigger decrease is achieved by the method of redistribution, which is based on the accounting of the differences between the measured and calculated pressures in the control nodes.
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References


