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Water distribution network analysis accounting for different background leakage models

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Abstract

This contribution analyzes the implementation of two widely used literature leakage models within an advanced pressure-driven hydraulic simulation model (WDNetXL system [1]). The used leakage modelling approaches are that introduced by Germanopoulos [2] and that proposed by Van Zyl and Cassa [3] based on experimental evidences under the assumption of linear elastic behavior of pipes. The modelling approaches are discussed from different perspective and tested on the hydraulic analysis of a literature network.

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Keywords: Background leakage modelling; Hydraulic analysis; Water distribution network.

1. Introduction

In recent decades, pressure management in water distribution network (WDN) has been recognized as essential for effective leakage management. Benefits of managing pressures range from water loss reduction, limiting the deterioration of network components (joints, valves, pipes, etc.), and to reducing frequency of new leaks in the network [4][5]. At the same time, the general development of information technology and the increase of computational capabilities coupled with the increasing interest for WDN analysis and management of water utilities, have led to significant advancement in WDN hydraulic simulation (i.e., WDN pressure-driven analysis).

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In this scenario, effective modelling of water leakages is essential for an accurate analysis of pressure management strategies through WDN simulation models and for efficient model calibration for existing WDNs [4][6], as well as for leakage detection techniques based on inverse analysis [7].

The starting point is that water leakages in WDN are directly related to pressure as well as to age and material of WDN elements (joints, valves, pipes, etc.). Therefore, a number of numerical models were developed starting from experimental observations and assuming the validity of the Torricelli law in the following form, which is valid for a single leak orifice,

$$Q_{leak} = C_d A \sqrt{2gP} \tag{1}$$

where Q_{leak} is the leakage flow rate through a hole of area A under a pressure head P; g is the acceleration due to gravity. The coefficient C_d is introduced in order to take into account that for real fluid the cross sectional area of the water jet is less than the orifice area, due to frictional energy losses.

However, evidences from field studies and implementation of pressure management strategies all over the world showed that the leakage rate into a WDN can be more sensitive to pressure than what said by the Torricelli law, with exponents for pressure head P in the range 0.5 to 2.95 [8]. This has led to assume that the effective area A_E can be pressure-dependent, in relation to the presence of various types of leaks, affecting different elements of the network, with materials of different deformability. Therefore, from the hydraulic modelling perspective, given the complexity of representing physically such a large number of individual leaks within the WDN (i.e., understanding the behavior of leaks individually), it is very important to rely on a model for leakage representation within the hydraulic simulation model, which is efficient for pressure management strategies and network model calibration.

The aim of this contribution is to compare and discuss two widely used leakage models from literature, also based on their implementation within a pressure-driven hydraulic simulation model, i.e., the WDNetXL system [1]. The used leakage modelling approaches are that introduced by [2] and that proposed by [3] based on experimental evidences under the assumption of linear elastic behavior of pipes.

2. Background on leakage modelling

Water distribution system losses may be classified as due to background losses (e.g., from joints, fittings, and small cracks), reported bursts, and unreported bursts [9]. Bursts are intended as major water outflow events that are usually reported to water utilities and repaired since they are likely to produce major service disruptions. For this reason burst are commonly considered as accidents whose impact on WDN can be limited by improving active leakage control and the efficiency of detection and repair actions. Vice versa, background leakages are intended as outflows running from small cracks, holes, deteriorated joints or fittings, occurring along pipes. As diffused water outflows, background leakages do not result into evident and quick pressure drops through the network, thus they are not reported and run for longer time, producing relevant impact in terms of WDN water lost volumes. For this reason background leakages can be reduced by planning medium-long term interventions for asset rehabilitation and pressure management. Therefore, the following formulations are referred to background leakages modelling.

In both cases, breaks along pipes can be assimilated firstly to orifices, and for them, originally, the Eq. (1) was considered valid. However, from several studies on real WDNs, it has been shown that the Torricelli law does not provide a satisfactory model for the relationship between leakages with pressure within a WDN.

As a result, leakage practitioners and water utilities adopted a more general leakage equation, which formally was proposed by [1][10] in the form of a power equation,

$$Q_{leak} = \beta P^{\alpha} \tag{2}$$

where P is the average pressure head on the element/segment of the WDN considered (e.g., the generic pipe, the pressure zone, the whole network). Variables α and β are two leakage model parameters, that represent the influence of some factors on the relationship leakage/pressure. Parameter β can represent the pipe deterioration over time, thus