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Emergency Management of Water Distribution Systems: the Nodal Demand Control

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Abstract

During emergency situations (e.g., due to pipe bursts or other network failures), appropriate management of Water Distribution Systems (WDS) is required. Critical events often cause service failures, because the pressure head in some nodes of the network become inadequate to deliver required demand. In this paper, a new methodology is developed based on the nodal demand control. with the aim to increase the pressure head, and hence the flow rate actually delivered at critical nodes (i.e., hospitals, vulnerable customers, etc.). This is done to avoid or minimize service interruptions between the failure and the repair times. Furthermore, a pipe burst can cause isolation of a portion of the network such that the flow along pipes changes and this causes the reduction of head in some nodes. The proposed methodology is manages the delivered flow rate using a Pressure Driven Analysis (PDA) approach. This is based on operating control of valves and by identifying the nodes where the pressure control should be implemented. Those control nodes are chosen by the analysis of sensitivity matrices and the Max-Sum Method (Bush and Uber, 1998; Fiorini Morosini et al., 2014). The methodology is demonstrated on a case study for a real network of Cosenza, a town in the South of Italy.

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Keywords: WDS Management; Water Network Analysis; PDA Analysis; Pipe burst.

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1. Introduction

Management of WDSs has been the focus of research and industry communities in recent years. This problem becomes prominent when one or more pipe failures occur in a network.

Pipe rehabilitation studies focus on preventing failures in pipe networks and ensuring the long-term system efficiency (Engelhardt et al., 2000). Optimization and decision support techniques linked to economic aspects, such as the minimization of the repair and maintenance costs (Lansey et al.,1992; Kleiner et al., 1998), or based on performance indeces of water network reliability (Gargano and Pianese, 2000; Berardi et al., 2008), can also be used.

Other studies have considered multi-objective genetic algorithm methodologies, which take into account economic and performance indeces (Farmani et al., 2005), while some management models are based on the time planning of repair and maintenance operations (de Marinis et al., 2008). Furthermore, the optimal sequence of these operations could be linked to the reliability maximization and costs minimization (Alvisi and Franchini, 2006).

This work presents a different approach to the problem and proposes a methodology for emergency management of water networks during the repair and recovery period. When a pipe burst occurs, it is necessary to isolate an area (district) of the network (Giustolisi and Savic, 2010) by operating a subset of valves. A critical area is a zone where the supply must be maintained (i.e., a district with a hospital or with vulnerable customers) even during service interruptions in other areas. The methodology is based on the definition of a new nodal demand distribution at sensitive nodes. The aim is to improve the head in the critical areas of the network and to increase the effective delivered flow. A PDA (Pressure Driven Analysis) model is used such that the delivered demand depends on the nodal pressure head (Calomino and Veltri, 1980) and the sensitive nodes are chosen using the sensitivity matrix approach (Fiorini Morosini et al., 2015).

2. Methodology

When a failure occurs in a WDS, it should be isolated by manipulating valves to allow the necessary time to repair pipe. Therefore, a new network configuration should be analysed to assess the impact of reduced total flow in the system.

Sometimes, the pipe failure produces a decrease of head in the network and in some nodes the demand flow rate (Qreq) cannot be guaranteed. In this case a PDA model, as INetPDA (Veltri et al., 2010), is more adequate than a Demand Driven Analysis (DDA) to analyses the system and to define the effective demand (Qfail) that can be delivered when the head is lower than minimum head Hmin. The aim of this paper is to describe a methodology to increase the pressure head in particular nodes of the network, defined here as critical nodes (i.e., hospitals, vulnerable customers, etc.). These nodes would otherwise not have enough pressure to deliver the required flow rate due to the failure. To increase the head value in critical nodes, the methodology proposes to limit the demand in the nodes with an adequate head and so to reduce the circulating flow in the network. This nodal demand check could be done using valves which control the head, and define a fixed flow at the node (Savic and Walters, 1995). To choose the nodes for the demand control sensitivity matrices are used. In this matrices each element represents the variation in pressure when a variation of the demand, Qi, at nodes or the roughness coefficient, εi, in pipe occurs.

The model employs the Max-Sum Method (Bush and Uber, 1998) and it is shown below (Fig. 1).