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Identification of appropriate resistance equation in analysis of water distribution networks

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Abstract

Water distribution system (WDS) analysis plays an essential role in calibration, design, management, and rehabilitation of pipe networks. Head loss calculation, as an important component of pipe network analysis, can be conducted via Darcy-Weisbach (D-W), Hazen-Williams, Chezy, and Manning equations. The D-W equation is the most accurate head loss equation since unlike other resistance equations, it not only satisfies the principle of dimensional homogeneity, but also varies with pipe flow dynamics. Although the Colebrook-White formula is an accepted head loss equation, it is implicit and consequently considered to be inefficient and cost-effective in WDS analysis. In order to address appropriate selection of resistance equation, the literature is filled up with many explicit approximate equations for which the potential user might wonder which equation to use for a certain condition. In this paper, the applicability of forty five explicit equations was compared by solving two test networks using the finite element method as solver. The results show that not only some of these equations are not reliable in WDS analysis but also they may cause converge problems. In light of the results obtained, a few appropriate resistance equations were identified to capture the dynamics of flow in an efficient way.

Keywords: Water distribution system analysis, Darcy-Weisbach equation, explicit head loss equation, finite element method.

1. INTRODUCTION

Analysis of flow in Water Distribution System (WDS) is considered to be an essential and inevitable part of any task intended to design and monitor a given pressurized pipe network. These tasks include but not limited to designing, sensor placement for monitoring, optimization, calibration, management and rehabilitation of such systems. As a result, the more efficient a pipe network solver becomes, the easier WDS analysis and design can be conducted and consequently implemented.

The WDS analysis aims at finding element flow rate (Q) in each pipe and hydraulic head (h) at each nodal point in the pipe networks. In reference to the nature of variation in flow rate in various elements, three different hydraulic conditions can be considered for WDS analysis. The steady state condition occurs when a constant loading condition is applied and the corresponding state variables remain invariant with respect to time. Extended-period simulation will be called upon if the nature of temporal variation is considered to be quite gradual whereby the simulation period can be decomposed into a few quasi-steady state sub periods. The transient situation, rapid change of flow characteristics, refers to unsteady flow conditions whereby both pressure and velocity fields vary with space and time in an erratic manner. In this paper, the steady state condition is considered as it is the most common and prevalent scenario in analysis and design of WDSs.

The conservation of mass and energy are the governing equations in various hydraulic situations including the steady state condition. Upon implementation of these conservation laws, four scenarios can be conceptualized depending on the nature of state variable(s) selected. The conservation laws can be cast in terms of flow rate in each pipe (Q), hydraulic head at each node (h), loop flow correction in each loop (ΔQ), and a combination of flow rate and hydraulic head in the entire network invariably called Q-based, h-based, ΔQ-based, and Q-h-based systems, respectively [1]. Regardless of the type of state variable chosen, the resulting governing equations are considered to be a system of nonlinear simultaneous algebraic equations to be solved numerically in order to find the velocity and pressure fields in the pipe network.

Energy loss in a given pipe network is considered to be a rule rather than an exception. It could manifest itself in two different modes: namely major and minor losses. As such, its proper and efficient computation is a must in pipe network analysis and design. In the corresponding literature, a few resistance equations are