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Uncertainty in the analysis of water conveyance systems

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Abstract

Conventionally, the design of water conveyance and distribution systems is based on the assumption that all the involved parameters are known a priori and remain unaltered throughout the life cycle of the system. This type of approach offers simplicity in the calculations by neglecting a variety of uncertainties which accompany the parameters and processes involved. However, significant uncertainties do appear during the analysis and design of these systems, such as the equivalent pipe roughness and the actual internal diameters of the pipes. Furthermore, the demands at the nodes of the system are dependent on several ambiguous assumptions which are not always met at the operation stage. To deal with these uncertainties, several mathematical data demanding approaches have been proposed in the past. In this study these uncertainties are incorporated in the analysis of the system, using the extension principle of the fuzzy sets and a new operation of the fuzzy subtraction. Based on the calculation of head losses for each branch of the system, the nodal heads are derived as fuzzy numbers. The proposed methodology, being a low data demand methodology, is illustrated by a numerical example of a water conveyance system.

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Keywords:water conveyance; pipe roughness; nodal demand; fuzzy sets; fuzzy algebra

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1. Introduction and basic notions

Water conveyance and distribution systems are in most of the cases branched pipe systems. During the design stage it is customary to analyse the system based on the assumption that all the involved parameters are known or can be calculated before the analysis and the design stage, whereas the values of these parameters remain unchanged throughout the life cycle of the system.

However, most of the involved parameters are accompanied by uncertainties which cannot be neglected at the design stage. Among the parameters of each branch exhibiting uncertainty are the pipe roughness, the internal pipe diameter and the required water flow through the system ([1],[2]).

A number of methodologies dealing with the uncertainties of these parameters exist in the related literature ([3],[4],[5]). The methods presented in [4] and [5] are restricted to small distances from the mean since they are based on the development of Taylor series around the mean values.

This paper is dealing with all these uncertainties using an innovative "low data demand" methodology based on the fuzzy sets and logic. In addition, the proposed methodology can cover a wider range of values around the mean values. Before presenting the proposed methodology, it is wise to briefly mention some of the most basic principles of the analysis of the branched water conveyance and distribution systems.

In the case of a branched pipe water system, since the flow at each branch can be considered known, the head at each node, *H*, can be determined directly by calculating and subtracting the head losses of the previous branch.

Nomenclature

$\tilde{A}_\alpha$	α-cut of the fuzzy set A
D	internal diameter of a pipe (m)
H	hydraulic head (m)
h_f	head losses (m)
k	pipe roughness coefficient (m)
L	length of the branch (m)
n	node
Q	flow at pipes (m^3/s)
q	outflow at the node (m^3/s)
μ	membership function of a fuzzy set (dimensionless)
v	kinematic viscosity of water (m^2/s)

Let, the nodes *i, n,* and *j* be three consecutive nodes of the main branch of a system moving from upstream to downstream. The flow downstream of the node n, Q_{nj}, is equal to:

$$Q_{nj} = Q_{in} - q_n \tag{1}$$

where q_n is the outflow at the node n.

The head at the node *n* is equal to:

$$H_n = H_0 - \sum_{0 \to n} h_f \tag{2}$$

where H_0 is the initial head (e.g. the elevation of the free water surface in a tank) and Σh_f is the sum of head losses calculated by equations such as the head loss equation of Darcy-Weisbach.