A spatial decision support system for pipe-break susceptibility analysis of municipal water distribution systems

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Abstract

Municipal water distribution maintenance is very important for sustainable urban development. Water pipe-breaks result not only in disrupting service but also in significant loss of water, which otherwise could have been sold to the consumer. In countries where water is scarce, such as South Africa, water losses can be detrimental to the living standard of people. Water pipe-breaks can furthermore cause extensive damage to nearby lower-lying properties.

Existing decision support systems available in the field of water distribution system maintenance mainly focus on leak detection and pipe rehabilitation/replacement strategies. These existing systems, however, do not address the actual causes of pipe-breaks.

This paper reports on the development of a spatial decision support system (SDSS) for pipe-break susceptibility analysis. The engineer (or public works administrator) can apply the SDSS to model the complex pipe-break phenomena in a municipal water distribution system in order to identify pipes susceptible to breaking. This should promote more informed decision-making on preventative maintenance measures to be taken and their prioritisation.

The SDSS has already been successfully applied to the water distribution system of Paarl (a medium-sized town in South Africa).

Keywords: pipe-break; pipe-break susceptibility analysis; water distribution system; pipe age; air-pockets; tree-roots; total break susceptibility, SDSS, GIS, fuzzy logic

Introduction

This paper reports on the development of a spatial decision support system (SDSS) for pipe-break susceptibility analysis of municipal water distribution systems. The SDSS can identify pipes susceptible to breaking and therefore promote more informed decision-making on preventative maintenance measures to be taken and their prioritisation. The rate of pipe-breaks in a water distribution system can thus be reduced. Newly planned water distribution systems can similarly be tested with the SDSS for high pipe-break susceptibility. In this way designs can be altered or improved before commencing with the actual construction. The SDSS also has special functionality incorporated for pipe-break impact assessment with regard to water loss (i.e. the modelling of the outflow rate at pipe-breaks) and possible damage caused to nearby lower-lying property (such as structural damage and the ruining of swimming pools, gardens, carpets, etc.). These two impact assessment functionalities, however, will not be discussed in this paper, since the focus of this paper will be on pipe-break susceptibility analysis only.

The SDSS design is based on the concepts of information systems theory, fuzzy logic, object-oriented modelling and pipe-break theory. The pipe-break susceptibility analysis model of the SDSS is based mainly on existing pipe-break theory (which is a highly specialised field in civil engineering) and fuzzy logic (the modelling of complex, interrelated factors where partial truth, i.e. the grey area between true and false, plays a significant role). The model has been tested and calibrated successfully (Sinske, 2002) by comparing the model results with the actual pipe-break occurrence data collected and made available by the Paarl Municipality, Western Cape Province, South Africa.

In the following sections the SDSS system functionality, the system architecture of the SDSS and finally, the system application are described.

System functionality

The SDSS has special functions and operations to support the following pipe-break susceptibility analyses, viz. pipe age, air-pocket formation and damage to pipes by tree-roots. At this stage, with the available digital data on the study area, only these three important pipe-break causes can be modelled accurately with the SDSS. The SDSS has, however, been designed in such a way that it can easily be extended to model most of the other pipe-break causes such as corrosion, aggression, low/high temperature, temperature differentials, differential settlement, external impact and pressure surges (Morris, 1967; Böhm, 1993; Sinske, 2002).

The SDSS users (e.g. the system administrator, SDSS operator, SDSS analyst and public works administrator) can access the system functionality on different user access levels. The graphical user interfaces (GUIs) will adapt accordingly so that only the relevant user functionality is made available.

The SDSS furthermore provides powerful object-query functionality and manipulation operations to explore the solution space. The system supports fuzzy logic-based analysis. Functionality is also included to combine the results of separate analyses by using a multi-factor evaluation process.

Additionally, the SDSS has functionality incorporated to compare model results with actual pipe-break occurrence. Hereby user-specified factor weights and the decision rules applied in the model can be calibrated.

Finally, graphs, cumulative distribution graphs and thematic maps of the model results can be compiled.

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