HYDRAULIC SIMULATION FOR ASSESSING LEAKAGE IN WATER DISTRIBUTION PIPELINES

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Abstract: Water distribution networks (WDNs) are one of the most expensive infrastructures in cities. They works delivering drinking water to different zones and types of consumers (residential, industrial, commercial, etc.), however deterioration process in elements such as pipes and valves in the network produces water losses via leakage through those components. Most of the hydraulic analyses in WDN are given by demand driven-analysis (DDA) with the assumption of known and satisfied nodal demands. In presence of leakage, outflow in nodes are influenced by reduction of the pressure in the network, therefore the use of DDA could bring unrealistic simulation from actual situation. It is important identify probable areas with some critical range of leakage in order to make maintenance procedures if it is required to accomplish some level of efficiency in performance, especially, in the case of networks with general deterioration in their infrastructure by oldness or not realistic hydraulic simulation analysis. This study introduces into hydraulic simulation the presence of leakage and considers unsatisfied nodal demand as functions of network level of pressure, in order to make a hydraulic model to define leakage areas around the network with more realistic nodal demand outflow. The model is applied to El Alto city's WDN (South America – Bolivia), which is known of having high level of leakage (around 30.2 % percent of total delivered water). Improvement of efficiency is critical to water management policies in networks like this area. The model developed here tries to help in reach that purpose.

1. INTRODUCTION

Water loss through the WDN is generally the biggest loss of water in the entire process for drinking water supply in a city (including the treatment plant, the pipeline from the water source, etc.). A typical leakage control program usually stars with a water audit based on available flow measurements, and most practical studies do not go beyond it, Guistolisi et al. (2008), also considering the cost and logistics of it, the need for alternative methodologies is required. Variables such as the type of material and the age of pipes are characteristics that influence the existence of leakage and which can help make a control of the WDN condition. Another way to address this problem is given by the inclusion of water loss in the hydraulic model. It is known that leakage is closely related to the pressure level in the system and pressure defines implicitly the nodal demand along the entire network.

The pressure variation in the network, due to presence of leakage in relation to normal expected levels reveals another important feature, when nodal pressure drops to a certain level known as *desired pressure*, nodal demand can only be partially supplied, as Liu Jun et al. (2013). These variables can help to establish the behavior of water loss via leakage in the network, in other words, demand and water loss as a function of pressure in the system. This study used a hydraulic model defined in terms of pressure driven demand (**PDD**), which estimated leakage and actual demand.

Keywords: Leakage, water distribution networks, hydraulic simulation, pressure driven demand

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The case study is a system network located in the city of El Alto in Bolivia which has a historical average water loss of 30.2% on the annual volumes recorded. Taking into account that several countries have an admissible loss of 25%, the need of leakage reduction is a priority in networks like this.

2. METHODOLOGY

The hydraulic model is developed taking into account the hydraulic simulation algorithm defined by Todini et al. (1988), which is implemented by the EPA (Environmental Protection Agency, U.S.A.) in EPANET 2 (Rossman 2000). The equations governing the hydraulic behavior are; the equation of conservation of energy eq. (1) (at pipes) and the equation of continuity (at nodes) eq. (2)

$$\boldsymbol{R} \cdot |\boldsymbol{Q}|^{n-1} \cdot \boldsymbol{Q} + \boldsymbol{A}_{pn} \cdot \boldsymbol{P} = -\boldsymbol{A}_{p0} \cdot \boldsymbol{P}_0 \tag{1}$$

$$\boldsymbol{A}_{np} \cdot \boldsymbol{Q} - \boldsymbol{q}_{act} = 0 \tag{2}$$

Where $\boldsymbol{R}$ represents the flow resistance coefficient of pipes (Hazen Williams, Darcy Weisbach etc.), $\boldsymbol{Q}$ is pipe flow vector, $\boldsymbol{P}$ is the vector of nodal heads, $\boldsymbol{Po}$ is vector of water level in tanks and reservoirs, and $\boldsymbol{Anp} = \boldsymbol{Apn}^T$, $\boldsymbol{Apo}$, are incident matrices representing the connectivity of the elements in a network of *np* pipelines and *nn* nodes (Guistolisi et al. (2008)) . The inclusion of nodal demand as a function of pressure and water loss is given as follows.

$$\boldsymbol{q}_{act} = \boldsymbol{q}_{actual} + \boldsymbol{q}_l \tag{3}$$

$$q_{actual_i} = \begin{cases} q_{i-design} & P_i > P_{i-ser} \\ q_{i-design} \cdot \left(\frac{P_i - P_{i-min}}{P_{i-ser} - P_{i-min}}\right)^{\frac{1}{2}} & P_{i-min} \le P_i \le P_{i-ser} \\ 0 & P_i < P_{i-min} \end{cases} \tag{4}$$

$$q_{l_i} = \frac{P_i}{2} \sum_k \beta_k l_k (P_k)^{\alpha_k - 1} \qquad P_k > 0 \tag{5}$$

Where P_{i-ser} is the minimum admissible level of pressure required for optimal consumption or design, P_{i-min} is the minimum hydraulic pressure required for flow occurs (zero), P_i is the actual pressure, $\boldsymbol{q}_{actual}$ actual demand, $\boldsymbol{q}_l$ the loss of water, and the outflow $\boldsymbol{q}_{act}$ through nodes. This system of equations can be solved by Newton Raphson method, if we simplify its components as $A_{pp}=\boldsymbol{R}\cdot|\boldsymbol{Q}|^{n-1}$ and we get;

$$\begin{bmatrix} A_{pp} & A_{pn} \\ A_{np} & \mathbf{0} \end{bmatrix}\begin{bmatrix} \boldsymbol{Q} \\ \boldsymbol{P} \end{bmatrix} = \begin{bmatrix} -A_{p0}P_0 \\ q_{act} \end{bmatrix} \rightarrow \begin{bmatrix} f_{ECL}(Q,P) \\ f_{FCL}(Q,P) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \rightarrow$$

$$\boldsymbol{F}_{WDN}(\boldsymbol{X}) = \mathbf{0} \rightarrow \mathbf{X}_{i+1} = \mathbf{X}_i - J(\mathbf{X}_i)^{-1} \cdot \mathbf{F}_{WDN}(\mathbf{X}_i) \tag{6}$$

Where $\mathbf{X} = (\boldsymbol{Q}, \boldsymbol{P})$, $J(\mathbf{X}) = \partial\mathbf{F}_{WDN}/\partial\mathbf{X}$ account, the state variables and the Jacobian of $\mathbf{F}_{WDN}$ respect of them respectively. Eq. (6) represents the iteration over the entire network simultaneously. In it, inversion of the Jacobian requires big computational work for large networks; similar procedure is carried out using sparse matrix method George et al. (1981), just as in EPANET 2.

All the above methodology has been developed using the Visual Studio 2010 IDE, under Visual Basic programming language. It has been used; code libraries defined in EPANET 2 Source Code written in C language (the routine for Sparse Systems Method).

3. RESULTS

The application of the model under PDD analysis has been applied in various trial networks of variable size to ensure its reliability. The main topic is the application on real distribution network (WDN of the city of El Alto, Bolivia, Tilata system) to assess leakage.

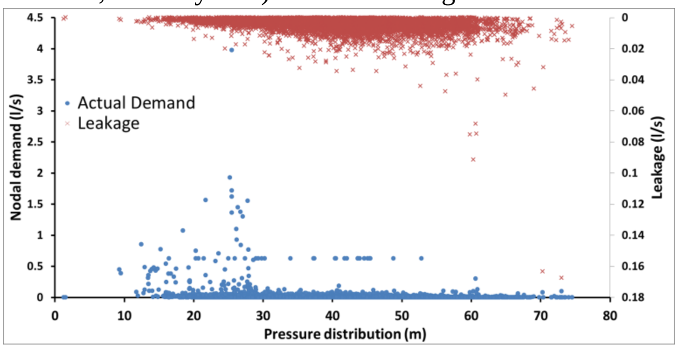

Fig. 1 Distribution of nodal demand and leakage

WDN Tilata comprises 10474 pipes, and nodes 9041. It has a historical loss of water of 30.2% of the total registered annual volume. The coefficients for the model are calibrated for that level of loss with $\alpha = 1.2$ and $\beta = 5.8502 \times 10^{-7}$ (Eq. (5)), and a permissible operating pressure of 15 m (P_{ser}). Data of design demands and characteristics of the distribution network have been gathered from the Ministry of Environment and Water of Bolivia (Coordinator Program for urban Water and Sewage MMAyA).

4. CONCLUSIONS

Generally along the entire network, presents a low average pressure in 19.60% from 50.78 m to 40.83 m, with respect to a constant nodal demand simulation. In addition an increase in the same proportion flows on pipelines reaches a limit of 179.38 l/s in the main matrix aspect that should be contrasted with the permissible criteria of the material in those parts of the network.

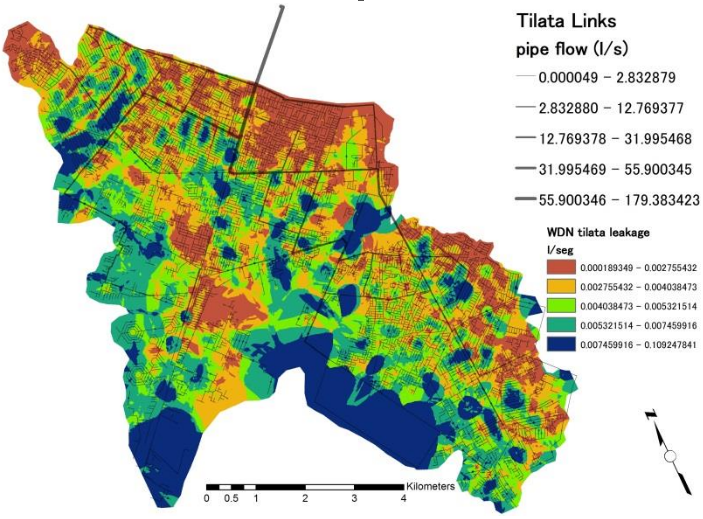

Fig. 2 Spatial distribution of potential leakage

As expected, distribution areas with potential leakage correspond to areas with high level of pressure but, not always. Connectivity and spatial distribution in infrastructure play an important role too (see Fig. 2). Classical assignation of losses in terms of nodal demand does not consider pressure condition; however, distribution of leakage around the network is highly correlated specially for critical levels (see Fig. 1).

5. REFERENCES

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