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Water Distribution Systems Analysis

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A network of pipes and hydraulic elements (valves, pumps, reservoirs) is considered solved when the heads and consumptions at all nodes in the network are known. Obtaining the solution, as defined herein, consists of finding the values of the specified unknowns which satisfy the following physical laws of the network: (1) Preservation of mass continuity at each node; and (2) that for each element there is a known relationship between discharge and energy gradient.

The Hazen-Williams equation, commonly used for water distribution studies, was selected as the law relating pipe discharge to energy loss. Other equivalent equations can be selected if desired.

Whether for the analysis of an existing network or for the design of a new one, the engineer needs the capability to solve for various combinations of unknowns, under many loading conditions. The analytical tools which have been developed to date make this task a lengthy and tedious process. The present work takes full advantage of the Newton-Raphson method to solve directly for combinations of unknowns which may include heads, consumptions, and element resistances. The method incorporates pumps, valves and other elements into the method of solution, without recourse to special external procedures.

The generalized steady-state solution of a water distribution network is but a small part of an over-all system analysis. Additional aspects such as acquisition, processing, storing, and retrieval of data, control and operation of a network, economic and social implications, and the effective use of digital computers will be described in another paper.

The following conclusions may be made:

1. A generalized method for solving a steady-state nonlinear network has been developed.
2. The method requires a high-speed computer of large capacity for effective practical utilization. Such computers are now (1968) available commercially for on-line, time-shared use or for batch processing.
3. The method's flexibility for handling changes in input data can be best used in a time-shared environment as an on-line tool to assist engineering design and decision making.
4. The method as implemented allows selection of unknown heads, consumptions or pipe resistances.
5. Problems without physical solutions may be specified by an inexperienced user because of the wide range of unknown types and locations which the method will handle. In order to have some assurance that a solvable network is specified, it is convenient to specify that at least one of the following is unknown at each node: (a) The consumption at the node; (b) the head at the node or at an adjacent node; or (c) The resistance of a pipe connected to the node. In practical use this rule is not usually inconvenient.
6. The method converges to a solution rapidly if a good set of initial guesses is made for the values of the unknowns. If a set of solutions is desired for slightly different conditions, it is advantageous to arrange the runs in a sequence which minimizes radical changes in system performance from run to run.
7. In some applications, it may be desirable to incorporate a sensitivity analysis into the generalized method to avoid needless iteration to study slight variations from a particular solution. The sensitivity analysis appears to be of particular value for use in real-time network operation by computer.

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