WATER DISTRIBUTION SYSTEMS ANALYSIS[a]

Closure

URI SHAMIR,[22] AND CHARLES D. D. HOWARD,[23] A. M. ASCE.—Discussion with others concerned with water distribution networks has indicated preferences for the Hazen-Williams equation, the Manning equation, and the Darcy-Weisbach equation with constant or variable coefficient. To date, however, in municipal water distribution systems, the preference seems unimportant in a practical sense, as the field data describing consumptions and head losses are generally estimated. The Colebrook-White transition function could be useful for certain types of networks, for gas or oil for example, for which good data is available.

Note that $(\partial Q_{ji}/\partial R_{ji})$ is computed for a change in R_{ji} itself. Only later does one decide whether it is D or k which will be varied.

McCormick is correct in stating that a separate procedure is required when the head difference along a pipe is small. This was indeed done in one version of SDP. Whenever the head difference was smaller than some preset value, the program set Q_{ji} to zero and $(\partial Q_{ji}/\partial H_j)$ to a very large number (10^5 was used). This is consistent with McCormick's remark, that the flow tends to zero, and the derivative to infinity, but contrary to his suggestion, stated in Eq. 33, to set the derivative equal to zero.

The writers do not agree with McCormick's comment that the method which applies corrections to all nodes simultaneously, is the same as that of computing the correction at each node separately, in the order in which the nodes are ordered. The Newton-Raphson technique is a method for solving a set of simultaneous nonlinear equations. The corrections are also computed simultaneously, thus embodying the effect of the unbalance at all nodes in computing the corrections. This is not to say that this procedure insures less computational work than, say, the one suggested by McCormick. It is stressed, however, that when all types of unknowns are present in a problem to be solved, the method of making individual corrections cannot be employed. This is because one cannot extract one equation of continuity from the set, and apply a correction to it alone. The equation may involve more than one type of unknown, say a consumption and a head, and the correction to both from this single equation cannot be determined. Rather, the complete set of equations has to be solved, which is what the Newton-Raphson technique does.

McCormick is correct in stating that Eq. 30 cannot be solved. Having selected the set of "free" variables for the sensitivity analysis as $X = (R_2, R_3, R_5, C_2, C_4)$, the conditions for solvability are not met. This is because for Node

[a] January, 1968, by Uri Shamir and Charles D. D. Howard (Proc. Paper 5758).
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1 none of the following are unknown: (1) C_1; (2) H_1, H_2, and H_5; and (3) R_1 and R_7.

The writers thank McCormick for pointing this out, which should have been done in the paper. There is no contradiction, however, between this example and the conditions for solvability.

As stated in the paper, a network cannot be solved if the rank of the A-matrix differs from the number of nodes. Since the paper was written, additional rules to avoid unsolvable networks have been found. The presently known rules are summarized as follows:

1. A node having an unknown consumption should be connected to at least one other node with a known consumption. This is because the consumption can only be determined to within a constant, i.e. there is an infinite number of solutions.
2. An unknown resistance is functionally dependant on unknown heads and consumptions at the terminating nodes. The subsystem consisting of an unknown resistance and two terminating nodes should not have more than one unknown in addition to the unknown resistance.
3. The rule stated in the paper: Considering any node, at least one of the following should be unknown: (1) The consumption at the node; (2) the heads at the node itself or at adjacent nodes; (3) the resistance of a pipe which connects to the node.

The writers are grateful for the results presented by de Neufville and Hester. The problem of convergence in the presence of pipes with sizes much different from all other pipes in the same loop has been known to users of the Hardy-Cross technique, and was found to be present in the Newton-Raphson technique as well. In practice one seldom has to solve an actual network where this is the case, as the engineer tends to deal with a skeleton network, made up of pipes of similar sizes.

The writers agree that more work should be done on the theoretical aspects of convergence of the generalized technique used in their program. Until such an analysis becomes available, practical guides have to be consulted. Programs for optimizing network designs, have to take into account the possibility of divergence during the solution of the network. Manual intervention in the program, when divergence occurs, seems the best answer for the time being. (When divergence is first encountered the possibility of a program or logic error should not be overlooked.)