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Discussion of "Method to Cope with Zero Flows in Newton Solvers for Water Distribution Systems" by Nikolai B. Gorev, Inna F. Kodzhespirov, Yuriy Kovalenko, Eugenio Prokhorov and Gerardo Trapaga April 2013, Vol. 139, No. 4, pp. 456-459. DOI: 10.1061/(ASCE)HY.1943-7900.0000694

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The authors of the discussed paper show a possible strategy for dealing with zero-flows in solving the nonlinear equations for water distribution systems when the Hazen-Williams equation is used. Recently, Elhay and Simpson (2011) presented a similar method for solution of the zero-flow problem also when the Hazen-Williams model is used, but they also explain and give a solution for the possible problem with zero flow when the Darcy-Weisbach model is used. In this discussion, a few simple remarks how to avoid the zero-flow problem in a network of pipes will be highlighted. Also, possible physical interpretation related to the problem will be explained.

Zero-flow in Hazen-Williams model

Both contributions, by the authors of the discussed paper and by Elhay and Simpson (2011), to the solution of the zero-flow problem when the Hazen-Williams model is used, cannot be disputed. Mathematical interpretation of the problem from both papers stands, but at the same time everybody has to be aware that the Hazen-Williams equation, used in both papers is obsolete and hence should not be used (Liou 1998, Brkić 2012a, Simpson and Elhay 2012). Zero-flow can occur when the Hazen-Williams formula is used since the coefficient is always independent of flow. The argument that the Hazen-Williams model can be used since it has been in common use for a very long time (Simpson and Elhay 2012), simply does not stand. The fact that the Hazen-Williams model is used for calculation in EPANET is also avoidable since this software equally allows the use of the Darcy-Weisbach model (Simpson and Elhay 2011, Brkić 2012a). Because the Darcy-Weisbach model with the Colebrook formula for the friction factor is theoretically more sound (Brkić 2011a, 2012b), the usage of the Hazen-Williams equation is strongly discouraged. Finally, the Darcy-Weisbach model can be used also for calculation of gas distribution networks, while the Hazen-Williams model cannot in any circumstances (Brkić 2009; 2011b,c).

Zero-flow in Darcy-Weisbach model

On the other hand, the zero-flow problem can occur when the Darcy-Weisbach formula is used only if laminar flow takes place (Elhay and Simpson 2011, Simpson and Elhay 2011, Brkić 2012a). This is because the resistance is independent of flow when the Darcy-Weisbach formula is in use only in the case of a laminar flow regime. So, knowing that laminar flow can occur only rarely and only in a few pipes of a water distribution network, calculation for these pipes should be perform as for the other pipes in which turbulent flow takes place. Further calculation with this assumption will not introduce significant error in the final result. Existence of pipes with laminar flow only means that the model of the network is not rationally planned. This subsequently means that diameters of these pipes have to be changed. Note that the network should be calculated for maximum possible nodal demands, which means that the network is rationally planned only if turbulent flow takes place in all pipes.

Analogy with electrical networks

It is true that laminar flow resistance in the Darcy-Weisbach interpretation is a constant for a single pipe (Elhay and Simpson 2011, Simpson and Elhay 2012, Brkić 2012a). This means that flow resistance, $r \neq r(\lambda)$, in the laminar regime does not depend on the value of the Darcy friction factor, λ (for the laminar regime, the Darcy friction factor can be calculated as $\lambda=64/R$, where R is the dimensionless Reynolds number). On the other hand, in the turbulent regime, flow resistance does depend on the Darcy friction factor, i.e. $r=r(\lambda)$ (where the Darcy friction factor can be calculated using the well known Colebrook formula). To make a point, a clear analogy with electrical resistance exists in the case of resistance in laminar flow. So, knowing that electrical networks can be solved in a non-iterative procedure using only Ohm's and two Kirchhoff's laws, it can be concluded that hydraulic networks can be equally solved using some sort of Ohm's law rearranged for use in hydraulic networks and two Kirchhoff's laws. Laminar flow resistance is independent of flow, but the whole calculation will be spoiled if even a single pipe of the hydraulic network has turbulent flow (a single pipe with turbulent flow renders impossible a non-iterative calculation of the whole network). In such a network, in which in all pipes laminar flow takes place, pipes with zero flow will be treated simply as a break in the circuit (a connection with infinity large resistance) or as a totally choked pipe, which will not cause any problem since no iterative procedure is needed.

Division by "zero" in computer environment

Computers today use the IEEE standard for arithmetic precision and therefore small numbers bellow a standard boundary will also be treated in the computer as zero which also can lead to the singularity of matrices used in calculation of water distribution network (Brkić 2012c, Sonnad and Goudar 2004). Also, use of software specialized only for matrix calculation (such as MatLab by MathWorks or even MS Excel) can be sometimes recommended as a better solution compared with the use of specially developed software for a water distribution network. In MatLab, it is possible to devise all parts of the calculation, while in a specialized software program for water networks, such EPANET, the designer is more restricted since the calculation procedures are already incorporated in the program code.

Possible physical interpretation of "zero-flow"

Although pipes with no flow in a real looped network of pipe can exist, it is more likely that a quite unrealistic model of a water distributive network is chosen if zero flow occurs (or the model does not accurately represent the system). Considering the network model from Figure 1 of this discussion which has a vertical axis of symmetry (symmetry in pipes diameters and nodal demands). Obviously such a network is excellent for the examination of the zero-flow problem. Symmetric networks can be found in Elhay and Simpson (2011) and in Álvarez et al. (2011). A symmetric network was referred to in the discussed paper in the work of Elhay and Simpson (2011).

Figure 1. Unrealistic symmetric model of water distribution network (chosen only for the examination of zero-flow problem)

To further illustrate the point of the shown zero-flow problem, the non-zero demand of node 2 of the network from Figure 1 is equal to with the demand of node 3, node 4 equal to node 5 and node 6 equal to node 7. Also, it can be assumed that all pipes have the same diameter. In that way symmetry of the network and symmetry of node demands leads to the logical conclusion that zero-flow takes place in pipes 2, 6 and 9. This subsequently leads to the conclusion that the consumer connected to pipes 2, 6 and 9 will suffer of water shortage since water users are really located between junctions (Figure 2).

Figure 2. Modeled versus possible real situation with two-way flow in a water distributive network

In reality, the consumers connected to pipes 2, 6 and 9 will almost certain have enough water since these pipes are supplied from two sides (two-way supplied pipes). Or in other words, the lowest pressure of water is somewhere between the two nodes (Brkić 2009). This situation is not allowed and cannot be calculated using any of the Hardy Cross type methods of s for calculation of looped pipe networks (Brkić 2011b). For example, the normal situation for pipe 5 is that water flows from node 3 towards node 5. This means that the pressure in node 3 is higher than the pressure in node 5 with a monotonically decreasing pressure through pipe 5. On the other hand, the pressures in nodes 2 and 3 of the network from Figure 1, are equalized which means that flow through pipe 2 is logically impossible. This assumption can be disputed knowing that the point of the lowest pressure (lower than in nodes 2 and 3) in reality is somewhere between these two nodes. This situation produces simultaneous flow from node 2 towards node 3 and also from node 3 to node 2 (two-way flow or simultaneous flow from two opposite directions). This is possible if the nodes in a model of the network are poorly spatially distributed. A good engineer should know that the real consumers are not concentrated in a node (Figure 2). They are actually distributed between nodes. Consumption concentrated in a node is only a model of the real situation. Also, nodes are not necessarily the only junctions in a network (Figure 3). In the network from Figure 1, nodes should be placed also between nodes 2 and 3, between nodes 4 and 5, and also between nodes 6 and 7 (nodes 9, 10 and 11 in figure 3 of this discussion). The actual situation of the demand pattern will in that way be modeled more realistically (Figure 3). It also has to be noted that an initially poorly conditioned network has as the consequence a poorly conditioned Jacobian which leads directly to a singularity in the related matrix.

Figure 3. Good conditioned node pattern in the water distributive network

The general recommendation is that the symmetry in a network should be avoided and if the symmetry exists, nodes at least should be always placed at the axis of symmetry (in that case a node should be placed at every point where pipes and the axis of symmetry cross each other). Symmetry of node demands and pipe diameters also should be avoided.

To conclude, temporary zero-flow rarely can occur in some of the pipes during the calculation of a looped network (virtual change of flow direction during the iterative procedure usually does not cause the zero-flow problem). But, if zero-flow remains as is at the end of the calculation, this usually means that the modeled network is not a good image of the real situation in the field.

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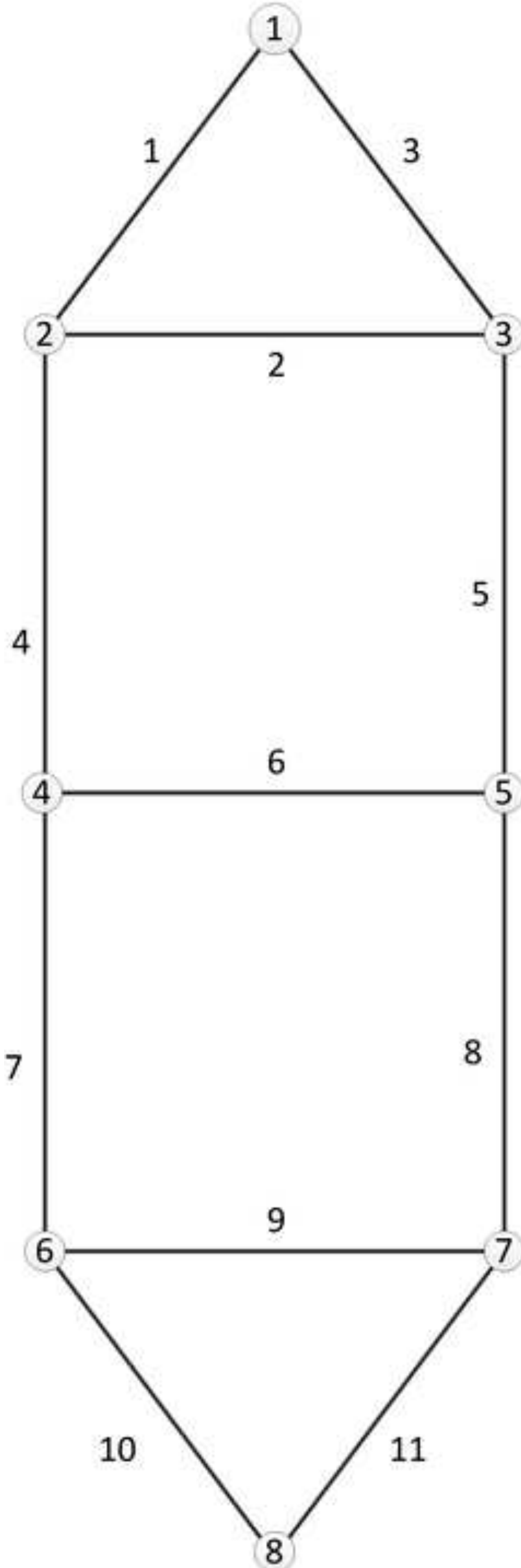

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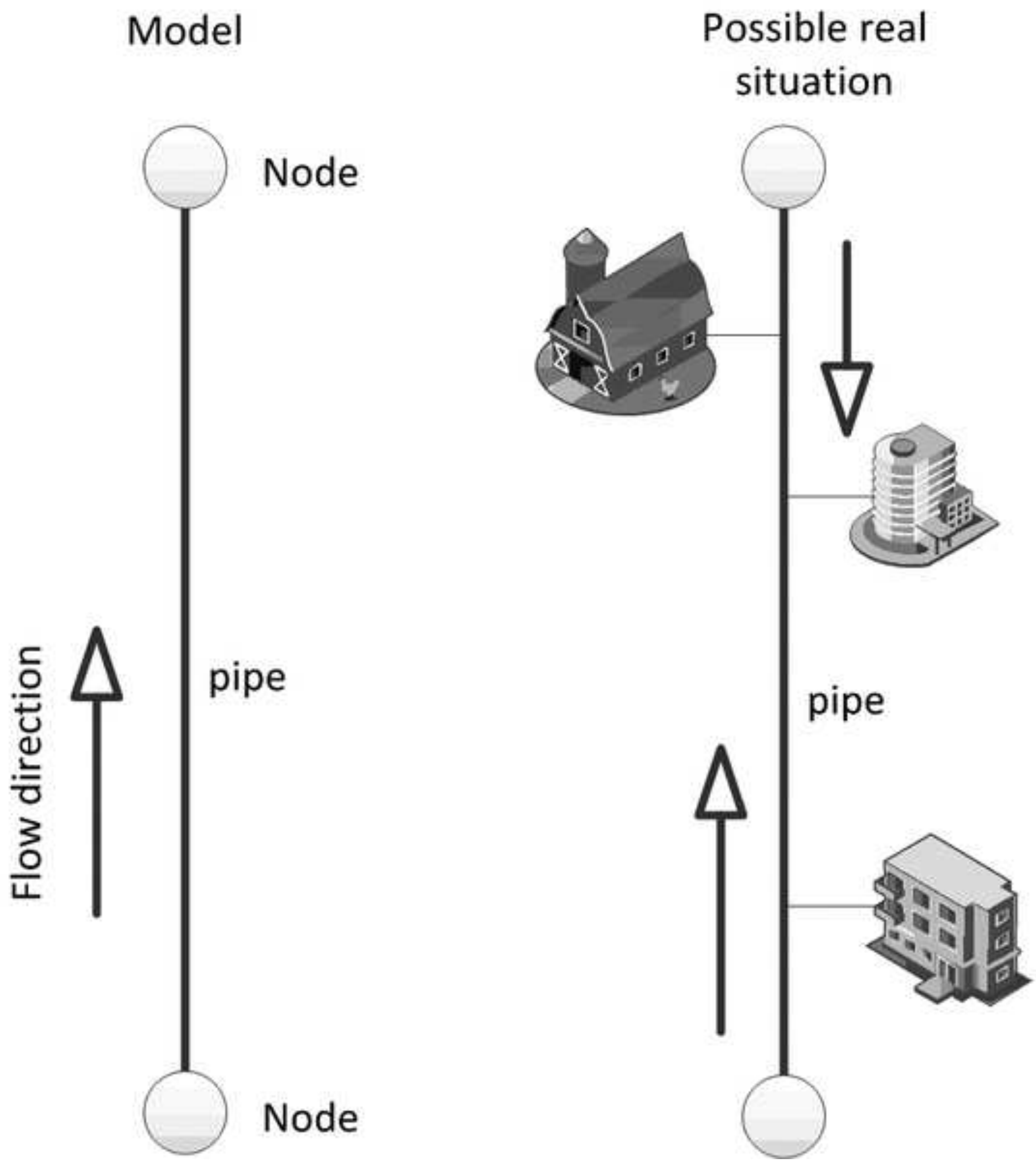

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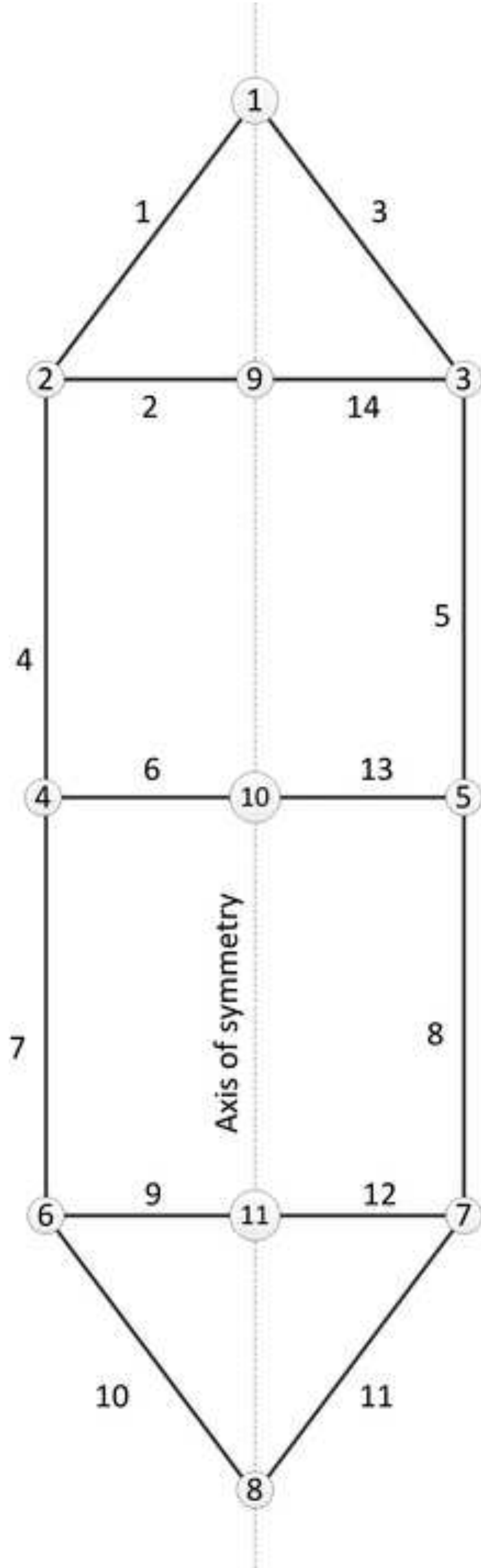

Figure caption list

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