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Sizing Up Gate Valve Hydraulics: Full Versus Reduced Waterway

Water utilities should consider several options when selecting assets for large-diameter valve applications.

BY JOHN R. HELF

AS THE United States continues to engage in much-needed infrastructure investment, safe and reliable transmission of water and wastewater will receive renewed focus. Current and future needs must be considered for pipeline construction and rehabilitation. Many population centers will require larger pipes and appurtenances than previously used. Representatives of these populations will find that sourcing material in larger, less common sizes is more challenging and costly. The reality is manufacturing these sizes is also more challenging and costly, and fewer manufacturers can produce in the largest sizes.

The valve market is no different. As the demand for larger sizes increases, user options are limited. The end user or engineer must sometimes make decisions about nominal valve and pipe sizes matching, and operators must ensure uninterrupted and unimpaired service to the public, regardless. These parties may have questions about the potential for reduced flow or increased head loss in different scenarios.

But how will a temporary reduction in gate valve waterway size affect the hydraulic performance of a complete piping system? The gate valves assessed here are of ANSI/AWWA C515, *Reduced-Wall, Resilient-Seated Gate Valves for Water Supply Service*, design. This is the most common large-diameter gate valve standard used in the United States today. Analysis will include both calculated and simulated data over various system scenarios in which a reduced-waterway and full-waterway valve are compared.

DESIGN OPTIONS

For an engineer or system owner, specifying gate valve options becomes significantly limited above the 48-inch nominal size. ANSI/AWWA C515 reflects this in allowing reduced waterway sizes in valves 54 inches and larger. For example, a 54-inch C515 gate valve is permitted to have a 48-inch diameter waterway. The 54-inch valve body would reduce to a 48-inch seating surface before expanding back to 54 inches on the opposite side. This allowance makes many internal components for the 54-inch valve interchangeable with the 48-inch valve, improving the practicality of offering products in larger sizes. Most gate valve manufacturers offering products above 48 inches use reduced-waterway valves.

Another option that may be considered is installing reducers on either side of a gate valve. This concept is like the reduced-waterway valve in that there's a temporary reduction in flow area. Using reducers may unlock more custom or project-specific solutions for the engineer or system owner. For example,

Table 1. Calculated Head Loss

Engineers calculate head loss to evaluate large valve design tradeoffs.

Scenario				System Effects		
Pipe Size *inches*	Nominal Valve Size *inches*	Valve Waterway Diameter *inches*	Pipe Fluid Velocity *ft/sec*	K_{total}	Head Loss *ft water*	Head Loss *psi*
54	54	48	5	0.21	0.08	0.04
54	54	54	5	0.03	0.01	0.005
66	66	60	5	0.10	0.04	0.02
66	66	66	5	0.03	0.01	0.005
84	72	72	5	0.21	0.08	0.04
84	84*	84	5	0.03	0.01	0.005

*The current scope of C515 ends at the 72-inch size.

Water utilities navigating system upgrades must weigh the tradeoffs of valve design and availability, especially as larger-diameter infrastructure introduces new hydraulic and sourcing challenges.

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AWWA gate valve standards currently don't exceed the 72-inch nominal size. The use of reducers to accommodate smaller gate valves in a larger pipeline has been a common practice for many years.

CALCULATED PERFORMANCE

A combination of product testing, system knowledge, and application of fluid mechanics makes possible a reasonable calculation of a valve's hydraulic impact. Fundamental to the calculation is understanding that any valve or fitting will have head loss from change in flow direction, obstruction in flow path, or change in flow path cross section. The pressure drop across a valve or fitting is referred to as a minor loss. Minor losses are in addition to major losses associated with pipe friction, and they are calculated differently. Minor losses can be calculated using the following equation, which can be found in many fluid mechanics handbooks:

$$h_L = \mathrm{K}\frac{v^2}{2g} \quad (1)$$

where hL = head loss through valve or fitting (feet of water); *K* = resistance coefficient, unique to each valve or fitting; v = fluid velocity through pipe (ft/s), and g = acceleration of gravity (32.2 ft/s^2).

Critical to calculating head loss through a valve or fitting is the understanding that the resistance coefficient, *K*, in Eq 1, varies significantly across valve or fitting type and size. Lower *K* values yield lower head losses. Generally, larger valves and fittings have lower *K* values. Less redirection or restriction of fluid also reduces *K*. This information is widely available for common appurtenances in smaller sizes and is derived from experimentation. For the sizes analyzed here, there are few, if any, public resources. Physical experimentation becomes impractical in the largest sizes. Therefore, several assumptions are made:

- Third-party experimental data for a 24-inch C515 valve is conservatively applied for larger sizes.
- *K* values for reduction and expansion of waterway diameter are approximated using applicable calculations in Crane Technical Paper No. 410, *Flow of Fluids though Valves, Fittings, and Pipe*: 4:1 reduction assumed for reducer fittings, per AWWA Manual of Water Supply Practices M11, *Steel Pipe: A Guide for Design and Installation*.
- The *K* values are added as necessary to produce a total *K* value.

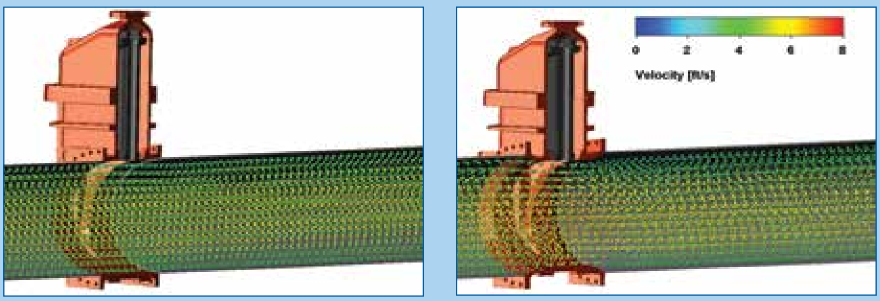
Given these assumptions, *K* values are determined for various scenarios as shown in table 1. Applying Eq 1 and using a reasonable fluid velocity speed of 5 ft/s, head losses are calculated.

Note the inclusion of a theoretical 84-inch C515 valve in this study. The market for C515 gate valves is trending larger as evidenced by the addition of 60-, 66-, and 72-inch valves in the 2020 edition of the C515 standard.

The calculated results of table 1 demonstrate two main points. First, a reduced waterway will have higher minor head losses than a full waterway valve. Second, and most important, the head losses are minimal in all scenarios. In other words, the differences would be undetectable using common field pressure-measuring devices. In the calculations, this result is attributed to low *K* values based on an open, unobstructed waterway and gradual reduction and expansion of waterway diameter.

Figures 1a and 1b. Simulated Flow Through a 54-inch Full- and Reduced-Waterway Gate Valve

Simulations reveal how a reduced-waterway gate valve (1a) temporarily accelerate flow compared to a full-waterway gate valve (1b)—an important consideration for water utilities evaluating hydraulic impacts in large-diameter systems.



SIMULATED PERFORMANCE

A newer technique for analyzing system fluid mechanics is computational fluid dynamics (CFD). The basic principles of CFD have been employed since the first half of the 20th century in applications ranging from submarine design to space-shuttle aerodynamics. This technique allows for detailed modeling of fluid flow through and around complex 3D geometry.

For this analysis, CFD simulation software (SolidWorks Flow Simulation) was used to better understand the effects of a temporarily reduced waterway through a gate valve. Computer-aided design models of table 1 configurations were assembled and simulated water flow set to 5 ft/s. Figures 1a and 1b illustrate that velocity temporarily increases through the reduced-waterway design before resuming its upstream velocity. The three reduced-waterway designs experienced a temporary fluid velocity increase of approximately 21%–36% relative to the full-waterway models. Table 2 shows the resulting pressure drop from each simulation.

The data generated from the simulations show there is a minor increase in head loss through a reduced-waterway gate valve versus a full-waterway gate valve. However, the pressure drop in each scenario is insignificant. These data echo the calculated results from table 1.

IMPORTANCE OF VALVE SELECTION

Both calculations and simulation data agree there will be a minimal increase in head loss through the reduced-waterway gate valve. The head loss is generally negligible in all configurations analyzed, and there's no decrease in flow in any of these scenarios. Fluid velocity temporarily increases through the reduced waterway. These results show that a temporary reduction in waterway using a gate valve has minimal impact on the hydraulic performance of a system. Note that this conclusion may not be applicable to other valve types with different geometry, such as butterfly or plug valves, which already have reduced flow area past the closure member. In those cases, the designer can expect higher head losses.

Valve selection is one of the most important aspects of any waterworks pipeline project. Gate valves have long been a preferred choice for their open, smooth waterway and low head loss. The results tabulated and described here confirm what decades of field experience have shown. To the owner or engineer designing a system in a larger, less common size, consider gate valves as a potential solution. To the operator, the same rules for valve operation and maintenance will apply for full or reduced waterways. Reference AWWA Manual of Water Supply Practices M44, *Distribution Valves: Selection, Installation, Field Testing, and Maintenance*. And as always, consult a trusted valve manufacturer that can help answer project-specific questions early in the planning process.

Table 2. Simulated Head Loss

Simulations quantify pressure drop from reduced-waterway valve designs.

Scenario			System Effects		
Pipe Size *inches*	Nominal Valve Size *inches*	Valve Waterway Diameter *inches*	Pipe Fluid Velocity *ft/sec*	Head Loss *ft water*	Head Loss *psi*
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66	66	66	5	0.03	0.01
84	72	72	5	0.1	0.04
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