Earthquake Resistant Ductile Iron Pipe, Valve, and Hydrant System

by Maury D. Gaston and Ryan S. Ratcliffe

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Abstract

Half the United States' population lives in an area of moderate to high risk of seismic activity.

Buried water lines are doubly important following a seismic event. Water is the first defense against fires, a major cause of additional destruction following an earthquake. Water is also essential for public health and the sustenance of life. We can exist without power for days, and many have done so, but when our supply of clean water is interrupted, we must soon restore it.

This is a presentation of a new joint assembly for fire hydrants, valves, and ductile iron pipe manufactured by AMERICAN Ductile Iron Pipe and AMERICAN Flow Control that provides for longitudinal joint expansion and contraction within limits of positive restraint, and radial joint deflection. Performance characteristics of the joint assembly will be noted and discussed, and the performance of ductile iron pipe, valves, and fire hydrants during seismic activity will be presented. A video of the joint in motion may be seen at http://www.american-usa.com/resources/videos/earth-quake-joint-system.

Introduction

While water utilities and communities strive to replace rapidly aging water service infrastructure and install new appurtenances to supply populations for generations to come, it is of the utmost importance that owners and operators be proactive and responsible with material and product selection. A responsible approach helps ensure current budgets are wisely allocated to materials that are long-lasting and dependable, standing the tests of time and environment. For example, when choosing waterworks materials, one is responsible to consider the conditions in which those products must perform and what environmental stresses and challenges they may experience during their time of service. Obvious conditions include static pressure, internal surge and external transient stresses, depth of cover, fatigue resistance, and other fairly well-known variables. Often overlooked performance criteria is the ability to withstand seismic activity, more commonly known as earthquakes. Fortunately, this need is growing in awareness.

At the 2014 ASCE Pipelines conference, the closing plenary session was led by Mark Knudson of Tualatin Valley Water District in the Portland, Oregon, area. (ASCE Pipelines Conference Program, 2014) In this presentation, Mr. Knudson presented sobering facts about the impact a major seismic event will have on lives, the economy, and even national security. In 2012, the Oregon legislature charged the Oregon Seismic Safety Policy Advisory Commission to develop a strategic plan to improve Oregon's ability to withstand and recover from a 9.0 temblor. The report predicted extensive damage to regional water supply systems and the near certainty of months to restore service. In his address, Mr. Knudson indicated some models predicted as long as two years for complete restoration of water services.

Seismic Overview

We all know water is crucial for public health. In fact, clean water is the greatest advancement in public health in the history of the world. We can inconveniently get along without power for some time, but not drinking water. The lack of safe and clean drinking water following an earthquake can result in widespread disease and death. (Lemonick, 2011)

In addition to providing the supply of clean water necessary for public health, the availability of fire protection in the immediate aftermath of an earthquake is crucial and cannot be overstated. As shown in Figure 1, damage from a post-quake fire, such as the one in Napa, California, is often more than damage from the seismic event alone. Damage from post-quake fires following the famous 1906 San Francisco quake is said to have been 90 percent of the total destruction. (SMS Tsunami Warning, n.d.)

Figure 1. Damage from a post-quake fire is often more than damage from the seismic event alone.

Because container water can be brought in, one can say that water for fire protection is more urgent immediately after an earthquake than clean drinking water. Regardless, the availability of a functioning public fire protection system and water supply following an earthquake will mitigate the fire damage and death toll tremendously. Hence, the need to further improve the survivability of common water distribution and fire protection systems.

Why is this important beyond isolated areas? The United States Geological Survey says that 50 percent of the United States' population lives in an area subject to moderate or severe risk of seismic activity. (Jaiswal, 2015) Further, the Washington Post recently reported that 28 million Americans live in areas of high potential and 58 million in areas of moderate potential. (Izadi, 2015) No matter which assessment you consider, a sizable portion of our population and economy is at some risk. Figure 2 provides a visual representation of seismic risk in the United States.

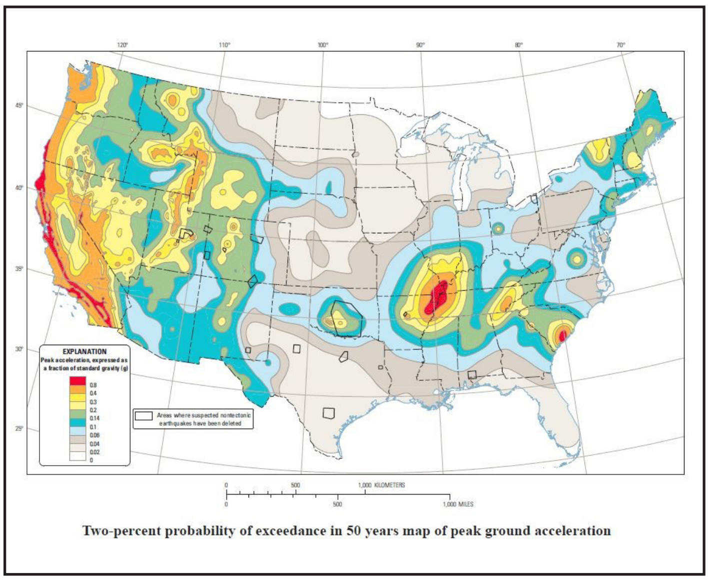

Figure 2. Seismic risk in the United States.

Let's look now at an overview of seismic phenomena. Generally speaking, there are three types of seismic activity: shaking of the ground, fault displacement or ground surface rupture, and ground failure such as liquefaction or landslides. (Housner, n.d.)

Damage from shaking is proportional to horizontal and vertical ground acceleration plus its duration. Fault displacement, or rupture of the ground, is when the earth moves up, moves down, or moves apart. Ground failure can occur at the surface or below ground and involves less solid mass, in other words material such as silt, sand, or gravel. This is common in areas of landfill, whether deep or shallow. Many high-risk west coast cities have substantial property built on fill. Figures 3, 4, and 5 are representative of these three phenomena.

Figure 3. Results of ground shaking.

Figure 4. Results of fault displacement.

Figure 5. Results of ground failure in the form of liquefaction.

In each of these dimensions of seismic activity, flexibility and strength are paramount to survivability. Buildings are designed and built to both sway and be strong. We should do the same for our underground public water supply by designing it to be flexible and capable of deflection and also capable of resisting end-wise separation.

Loma Prieta Earthquake and San Francisco's Infrastructure

On October 17, 1989, at 5:04 p.m. local time, what has become known as the "World Series Earthquake" struck San Francisco. Many in the waterworks industry were in town for the WEFTEC conference, including

Gaston, co-author of this paper. Here are some facts about that event:

- It was originally measured as a 7.1 temblor, but many have reduced it to 6.9, still a substantial quake.

- 102 water main separations occurred.

- 69 water main separations were in the 40-block marina district, a fill area subject to liquefaction.

- 26 fires were documented. (Stover, 1993)

San Francisco has three layers of water supply related to fire suppression:

- the municipal water system owned and operated by San Francisco Water Department,

- the Auxiliary Water Supply System, built by the San Francisco Fire Department,

- the Portable Water Supply System.

The auxiliary system is about 120 miles in length and was built following the 1906 earthquake and the resultant fires. It can be fed by gravity from reservoirs atop Twin Peaks at an elevation of 750 feet. It is made of both gray iron and ductile iron pipe, and while old, it was built with foresight and includes restraining rods at fittings and other points of likely stress. Restraining rods were used because its construction preceded the availability of self-restraining joints available today. It represents the best available materials and technology at the time, and this presentation includes significant innovative developments since then. The portable water supply system was developed in the 1980s and is a large-diameter hose system carried by fire trucks and fed from the nearby bay or ocean. (Scawthorn, 2005)

Earthquake Joint System Overview

West Coast personnel made known to AMERICAN their desire to have an earthquake resistant system for both pipe joints and for valves and hydrants. An imported product for pipe was available in metric dimensions,

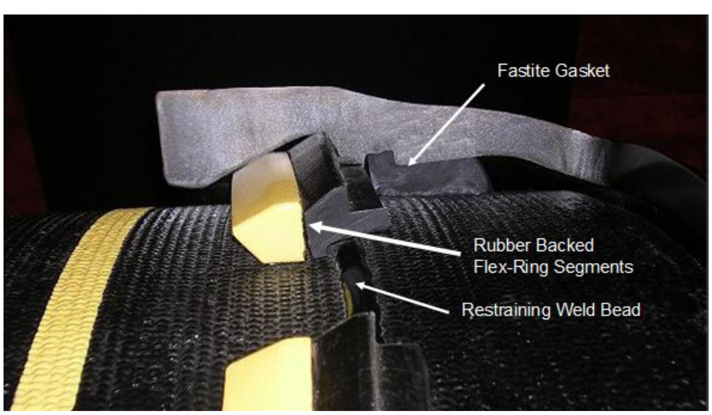

Figure 6. The AMERICAN Flex-Ring joint.

but nothing was available for valves and hydrants and nothing for pipe in domestic dimensions. We bench-marked against the ISO 16134 performance levels and developed the system for pipe, valves, and hydrants using the proven AMERICAN Flex-Ring joint as a foundation. A cross-section of this workhorse joint is shown in Figure 6.

Ductile iron pipe in general and its modern joints in particular are uniquely suited for survivability in the demanding conditions of an earthquake. Ductile iron is the toughest, strongest, most robust material available in the wide range of water distribution sizes. (Material Comparisons, n.d.) The typical push-on joint for ductile iron materials, whether the Fastite® or the Tyton® brand, typically has 5 degrees deflection in smaller and mid-range diameters. This translates into 21 inches offset across a 20-foot length. That offset compounds and provides tremendous deflection capability throughout a system. An entire circle can be made with 20-foot joints of 30-inch and smaller diameter ductile iron pipe with no fittings in a radius of just 230 feet (American Pipe Manual, 20th Edition, page 2-9.) These push-on joints are available for pipe, fittings, and hydrant connections, and a deflected AMERICAN Fastite joint is depicted in Figure 7.

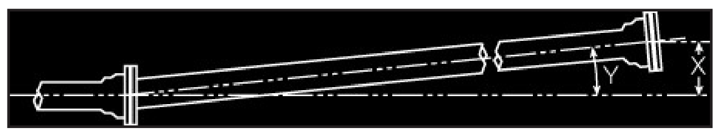

Figure 7. Five degree deflection depicted for a 20-foot length of pipe.

When longitudinal (end-wise) restraint is added to deflection, a joint suitable for seismic survivability begins to develop. A substantial breakthrough in seismic performance occurred in 2015 when AMERICAN® developed an Earthquake Joint System® that includes the deflection capability of more than the previously-available 5 degrees, the end-wise thrust resistance of Flex-Ring® and Fast-Grip®, and the performance of both expansion and contraction exceeding 1 percent of each pipe length. In other words, the AMERICAN Earthquake Joint System deflects, expands, contracts, and resists separation. To make this system complete, it is available for fire hydrants, isolation valves, and pipe.

The AMERICAN Flow Control Earthquake Joint Fire Hydrant System

Similar to a standard fire hydrant lead in terms of components, but drastically different in the sense that it allows for joint deflection and movement during settling and seismic events, the AMERICAN Flow Control Earthquake Joint Fire Hydrant system, shown above in Figure 8, is designed to maintain water pressure, conserve water, and provide reliable fire protection. Comprised of an AMERICAN Flow Control B-84-B-5 fire hydrant, an Earthquake Joint System hydrant base, an earthquake joint ductile iron connecting pipe, and an AMERICAN Flow Control Series 2500 Resilient Wedge Gate Valve with Flex-Ring ends, this system allows for over 13 degrees of lateral deflection in any direction, +/- 2.4 inches of longitudinal expansion or contraction, depending on the setting at installation, and is designed to withstand up to 100,000 pounds of pull-out thrust.

Figure 8. The AMERICAN Flow Control Earthquake Joint System for hydrants.

The Fire Hydrant

The AMERICAN Flow Control B-84-B-5 model fire hydrant shown in Figure 9 has commendably served communities throughout the United States and abroad for many years. The fire hydrant complies with ANSI/AWWA C502 and C550, has a rated working pressure of 250 psig, is certified to NSF/ANSI 61 and NSF/ANSI 372, and is the only fire hydrant in the industry to feature a positive compression drain that closes the hydrant drain system within three turns.

Figure 9. The AMERICAN Flow Control B-84-B-5 model fire hydrant.

The Hydrant Base

The AMERICAN Flow Control earthquake joint system base is a revolutionary joint that works in conjunction with earthquake joint ductile iron pipe to allow inlet pipe to deflect at an angle and move in and out of the fire hydrant base. The earthquake joint base, shown in Figure 10, allows up to 3 degrees of lateral deflection and +/- 2.4 inches of longitudinal expansion or contraction, or a total range of longitudinal motion of 4.8 inches. Made of ductile iron and coated with fusion bonded epoxy, this hydrant base is designed to withstand more than 100,000 pounds of pull-out thrust. The hydrant, shown in Figure 9, features a unique all-bronze drain ring with a series of lugs that allow the EQ hydrant® to help prevent the valve from separating in the event the lower and upper barrels become disengaged. This one-of-a-kind feature works with the dry-barrel design to allow system water pressure to remain in check. Water pressure, of course, is necessary for the operation of the hydrant. The hydrant base connects to the pipe with the adaptive Flex-Ring joint.

Figure 10. The AMERICAN Earthquake Joint System hydrant base.

The Ductile Iron Pipe Connector

A pup section of ductile iron pipe with an adaptive earthquake joint end and a conventional Flex-Ring end serves as the connection between the earthquake system hydrant base and the AMERICAN Flow Control Series 2500 Resilient Wedge Gate Valve.

The Gate Valve

The AMERICAN Flow Control Series 2500 RWGV (resilient wedge gate valve), shown in Figure 11, meets and exceeds ANSI/AWWA C515, features full ductile iron construction, and is rated to 250 psig. The valve is UL Listed and FM Approved in applicable configurations and certified to NSF/ANSI 61 and NSF/ANSI 372. The valve joint featured in the Series 2500 RWGV used in the Earthquake Joint System is the AMERICAN Flex-Ring joint. The Flex Ring joint is ideal for deflection in dynamic soil conditions, and on a 6-inch Series 2500, offers 5 degrees deflection and rotation at each joint, allowing liberal but controlled movement during a seismic event.

Figure 11. The AMERICAN Flow Control Series 2500 RWGV with Flex-Ring ends.

The AMERICAN Ductile Iron Pipe Earthquake Joint System

As with the hydrant lead, the pipe in the Earthquake Joint System combines the rugged, resilient, and time-proven deflection performance of the Flex-Ring joint with the capacity to expand and contract, and yet resist end-wise separation. This is the culmination of joint innovation down through the years – joint restraint, joint deflection and rotation, and now joint expansion and contraction. These three dimensions of joint technology are required for seismic resistance, and this system meets them all.

All aspects of the AMERICAN Earthquake Joint System meet the applicable requirements of ANSI/AWWA C150 (design), ANSI/AWWA C151 (manufacture), ANSI/AWWA C111 (joints), ANSI/AWWA C153 (fittings), and ANSI/AWWA C104 (lining). They are to be installed in accordance with AWWA C600 and may be encased in polyethylene wrap in accordance with AWWA C105, including V-Bio enhanced polyethylene encasement.

The AMERICAN Earthquake Joint System for pipe is built around a central ductile iron earthquake casting that features an extended socket allowing the specially placed Flex-Ring weld ring an expansive range of motion. That casting is the middle piece of the assembly shown in Figure 12.

Figure 12. The AMERICAN Earthquake Joint System for pipe.

The central earthquake casting has a zinc-rich or zinc-clad coating applied directly to the surface at the factory. To indicate its unique role in earthquake survivability, the central earthquake casting is red in color. A section detail of the central earthquake casting is shown in Figure 13.

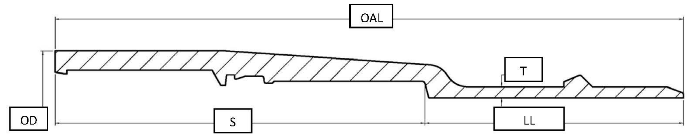

Figure 13. Cross-section detail of the central earthquake casting.

Concerning zinc, another recent and substantial innovation of interest is the availability of zinc-coated ductile iron pipe. Zinc has been used to extend the life of ferrous materials for many years and is now available on ductile iron pipe manufactured and delivered within the United States. A photograph prepared to show zinc basecoat and its topcoat on ductile iron pipe is shown in Figure 14.

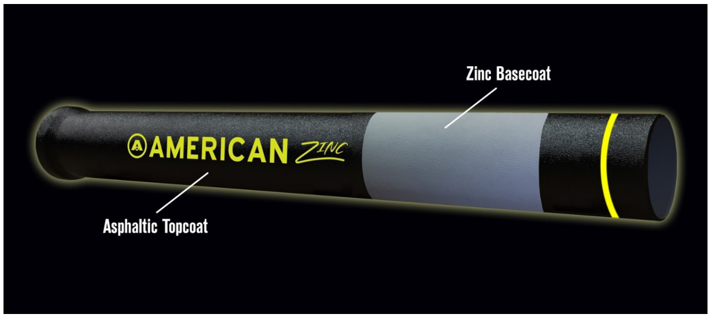

Figure 14. A specially prepared pipe showing zinc basecoat and finishing topcoat.

The ductile iron earthquake casting and AMERICAN Flex-Ring connecting piece arrive at the jobsite pre-assembled by professionals at the manufacturing plant. Prior to shipment, the extended socket receives a Flex-Ring spigot with a set-back weld ring. The pre-assembled AMERICAN Flex-Ring spigot has a double stripe, one showing full insertion and the other mid-point insertion.

Pre-assembly means the on-site contractor only needs to assemble the familiar and conventional Flex-Ring joint. In this application, the Flex-Ring spigot on the central ductile iron earthquake casting is red in color and the restraining spigot ring is machined instead of a weld bead. With respect to assembly and dimensions, it's a standard AMERICAN Flex-Ring joint and is assembled by the contractor in the field in that same familiar manner.

As with the hydrant connection noted earlier, the joint may be assembled in the fully contracted position allowing for maximum joint expansion of 4.8 inches, in the mid-point position allowing for 2.4 inches joint expansion or contraction, or in the fully extended position allowing for 4.8 inches joint contraction. The more common installation position is at the mid-point, which allows for both joint expansion and contraction of 2.4 inches either way during a seismic event.

Figure 12 shown previously depicts the earthquake assembly for pipe, and Figure 13 is a section detail. The right end of the central casting consists of the conventional Flex-Ring joint and may be deflected or rotated 5 degrees. The left end is assembled prior to shipment and consists of a deeper socket providing the expansion or contraction functionality and may be deflected or rotated 3 degrees. So with a laying length of the central casting of just slightly more than 2 feet, the AMERICAN Earthquake Joint System for pipe provides 8 degrees deflection or rotation in any direction and 2.4 inches contraction or 2.4 inches expansion, a range of longitudinal motion of 4.8 inches.

A Plan for Seismic Areas

The danger of high seismic activity is too challenging to predict, but here is a general plan that will strengthen your system and provide greater assurance to your community during dangerous episodes of seismic activity. Of course, all plans must be evaluated individually, and there is no one-size-fits-all. To be clear, Figure 15 shows a high-level generalization.

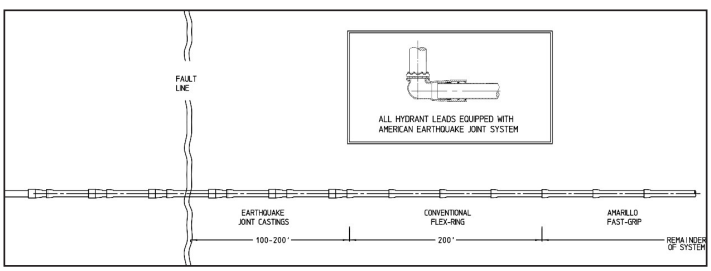

Figure 15. A general site plan representing various levels of seismic resistance moving outward from a fault line and engaging all hydrant connections.

At all fire hydrants, use a fire hydrant lead employing the AMERICAN Earthquake Joint System, which consists of a Flex-Ring gate valve, adaptive pup ductile iron pipe, earthquake hydrant shoe, and an AMERICAN Flow Control B-84-B-5 Model Fire Hydrant.

At all fault line crossings, use the AMERICAN Earthquake Joint System for pipe at the fault line, and every 22 feet outside the fault line for a distance that makes you comfortable, 200 to 300 feet on each side of the fault line, or further, for example. This will provide 8 degrees deflection and rotation and 2.4 inches, more than 1 percent of longitudinal expansion or contraction, at a number of locations immediately adjacent to the fault line. You may then choose to use an earthquake assembly between every other pipe length, every third pipe length, etc., with conventional AMERICAN Flex-Ring pipe joints in between the earthquake assemblies.

From there, and continuing to move outward from the fault line, use the conventional Flex-Ring joint with 5 degrees flexibility. As you continue to move beyond the area of greatest seismic risk, employ the Amarillo® Fast-Grip restrained joint gasket pictured in Figure 16. This is used in the conventional Fastite joint ductile iron pipe and provides simple and field-adaptable joint restraint with a gasket employing teeth that keeps the joint together while providing 5 degrees deflection and rotation. It's a topic in and of itself, but more Fast-Grip information can be found online at: http://www.american-usa.com/products/ductile-iron-pipe-and-fittings/gaskets/amarillo-fast-grip-gaskets.

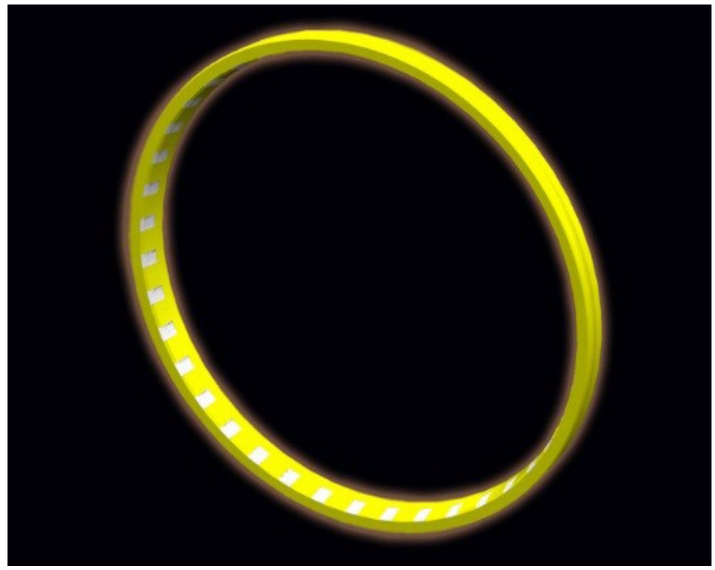

Figure 16. The AMERICAN Amarillo Fast-Grip gasket for deflection and thrust restraint of Fastite joints.

A plan view illustrating this concept of beginning at the fault line and working outward employing various levels of seismic resistance is shown above in Figure 15.

Conclusion

Employing this rationale and these innovative AMERICAN pipe, valve, and hydrant products, you will have a well-designed system that could be envisioned as a strong underground flexible web of piping and valves. You will have dependable fire protection throughout that web, and a water supply network possessing joint flexibility, end-wise resistance, and longitudinal capacity for contraction and expansion. You will be better prepared to answer the question posed in Figure 17.

Figure 17. Will water be there for your firefighters?

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About the Author

Maury D. Gaston is a 34-year veteran of the water industry and a member of the American Society of Civil Engineers and the American Water Works Association. In April of 2016, ASCE presented him with an innovation award for his writings on trans-basin pipelines. Within AWWA, he is a member of the A21 committee concerning ductile iron pipe products and chairs sub-committee 1 dealing with design and manufacturing standards of ductile iron pipe.

Mr. Gaston has held numerous sales and marketing responsibilities across the country during his career at AMERICAN, and is currently Manager of Marketing Services for AMERICAN Ductile Iron Pipe and AMERICAN SpiralWeld Pipe.

Mr. Gaston is also a Director and past Chairman of the state of Alabama Engineering Hall of Fame, and has served as Chairman of the Auburn University Alumni Engineering Council. He was recognized as Auburn's 2014 Mechanical Engineering Alumnus of the Year.

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Ryan S. Ratcliffe joined AMERICAN Flow Control in 2009 as a sales representative covering eastern Virginia, Maryland, Delaware, and the panhandle of West Virginia. The Tampa, Florida, native graduated from the University of South Florida, earning a Bachelor of Arts with a concentration in advertising. While at USF, Ryan was a member of the Phi Sigma Theta National Honor Society.

Ryan continues a legacy by becoming the third generation in his family to work in the water-works industry and is a second generation employee of AMERICAN Flow Control.

Ryan was promoted to Manager of the Western Area in September of 2014 and resides in Roseville, California, is an active member of AWWA, and serves on the Future Leaders Council of WASDA.

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