Flange Joints: Avoiding Installation Pitfalls

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Abstract

In the design of water pipe systems, bolted flange joints are usually given minor consideration in the overall scheme of things. Flanges have been successfully used in various types of pipe materials for over 100 years and their forms have been standardized for over 50 years. Most flange joint installations are completed without problem or concern, but when a complication arises, it can rapidly become a major issue for everyone involved.

Most anomalies that arise during the service life of a flange joint are rarely due to erroneous design; they are almost always related to poor installation practices. This paper discusses installation issues that may occur with steel water pipe flanges, manufactured to AWWA C207 standards. Topics such as proper bolt and gasket selection, flange face arrangements, alignment during installation, bolt-up patterns and the relationship between applied bolt torque and achieved gasket stress are discussed, and practical recommendations are provided to avoid some of the common installation pitfalls. A comprehensive list of resources for the Practitioner is provided, along with a discussion of recent updates in various flange standards and guides. Water system owners, design engineers and installation contractors alike will benefit from the contents of this paper as a resource to achieve leak-free bolted connections on future projects.

Introduction

AWWA C207 "Steel Pipe Flanges for the Waterworks Industry" has been the standard for water pipe assembly, with only minor changes, since 1955. So comprehensive is the variety and size range of these standard joints and so successful has been their history that only very rarely is it necessary for custom designs to vary from the norms. The current version of the standard, AWWA C207 (2013) not only indicates the standard flange specifications but dictates the only acceptable bolt, nut and washer grades respectively, and limits the choice of gaskets to one of three normally interchangeable materials for water service. Usually therefore, when problems arise they can be traced to poor installation practices rather than poor design or direct failure of the component parts.

Installation problem areas

Successful pressure joints are a combination of compatible flanges, fasteners appropriately tightened, and gaskets. Let's consider some of the most common installation challenges in that same order.

Flange-related installation issues

Standard water pipe flanges are of the flat-face (also called full-face) variety, the flange slips over the end of the pipe and is attached with internal and external fillet welds, see Figure 1. The gasket contacts the entire mating faces (full face gaskets) or the gasket fits inside the bolt circle (ring gasket), see Figure 2. This simple design maximizes the gasket-to-flange surface area and is ideal for the relatively soft gasket materials used in water service.

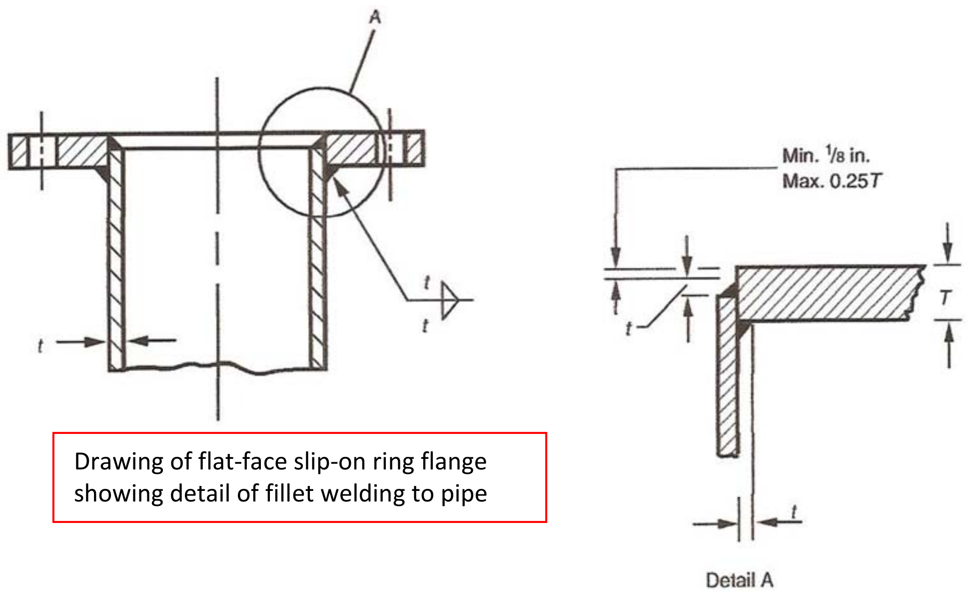


Figure 1 AWWA C207 Flat Face Flange

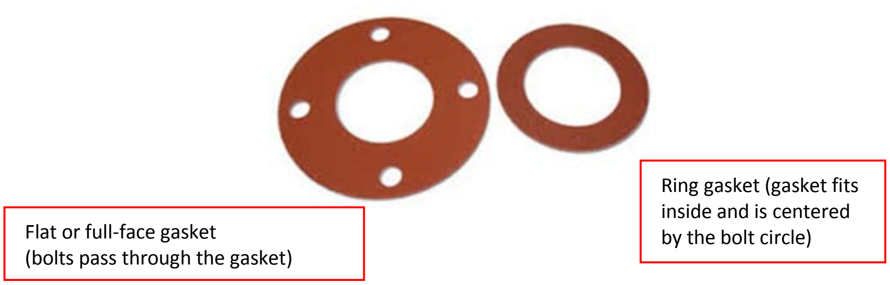


Figure 2 Full Face and Ring Style Gaskets

Correct specifications and condition

Even though there are not a lot of options for the installer to choose, care must still be taken to verify the pressure class, nominal pipe diameter, surface finish and any layback specifications ordered for the job. Flanges must be impression stamped on their circumference indicating the name or trademark of the manufacturer and with its AWWA Class as defined in Tables 2 through 5 of the standard. The classes with their nominal pressure ratings are: Class B (86 psi); Class D (175-150 psi); Class E (275 psi); and Class F (300 psi). Requirements for welding to the pipe are also detailed in the standard. An inspection of the gasket contact surfaces for damages or defects should be made. Particular attention should be given to any scratches which cross the sealing surface or which otherwise might jeopardize the seal. Prior to installation flanges should be stored in such a way as to protect the faces from damage. The term “flat-faced” does not refer to the smoothness of the sealing surface. Flat flange facings are machined and may be either phonographic (spiral) serrated or concentric serrated. The industry standard is a phonographic serrated finish. The aggressiveness of the serrations is typically measured by the Root Mean Square (RMS) or the Arithmetic Average Roughness Height (AARH) of the grooves expressed in micro-inches (μin). AARH and RMS are different methods of calculation giving essentially the same result and are used interchangeably for these products. The standard industry roughness for water flanges is 125 to 250 μin although smoother or rougher finishes are available at the user’s request.

Mating with other joint components

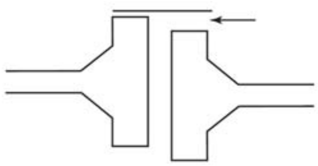
Water pipe flanges should normally only be coupled to identical flanges using studs or bolts with washers on both sides of the joint and nuts. Direct connection to valves, pumps, tanks or other machinery using bolts screwed into threaded holes, or bolting to other types of flanges should only be undertaken after careful study and in the light of successful experience. The effects of vibration, non-symmetrical gasket faces, dis-similar materials, galvanic compatibility, and lack of sufficient bolt flexibility are just some of issues that might affect the long term integrity of such a joint. If standard forged steel flanges absolutely have to be bolted to flanges of different materials such as cast iron, brass or fiberglass-reinforced plastic, for example, great care must be taken to adjust bolt loads to the strength of the weaker of the two materials. Soft metals and plastic flanges may exhibit a phenomenon called “creep” or “cold flow” where due to the high point loads under the tightened nuts the material thins causing a significant loss of bolt load resulting in leaks which may not appear until hours or days after initial installation. The advice of a qualified engineer familiar with the behavior of materials under pressure should be sought in these cases.

Alignment

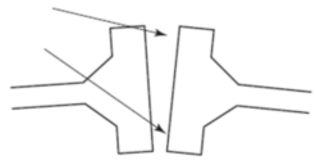
Perhaps no flange issue is so common or as critical as ensuring proper alignment of the joint before tightening.

Misalignment can include any one or a combination of the following:

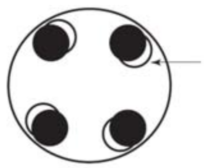
Centerline Hi/Low



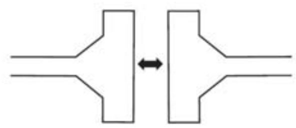
Parallelism



Rotational-Two Hole



Excessive Spacing or Gap



If both ends of the flange joint will be fixed during installation and will not allow for adjustment in the alignment of the joint, one side of the joint should be left unwelded or "loose" prior to fit up of the joint. This will allow the flange to be fitted in place and checked for gross alignment before being welded to the pipe joint so that bolt hole alignment, and correct distance between the flanges can be verified. Axial alignment of the pipes and parallelism of the faces of these slip-on flange faces must normally be achieved by adjusting the pipe supports.
Bolts are not meant to be used to align the joint. That should be done by moving the pipe and any necessary artificial forces used to bring the flanges into position must be maintained until the joint is finally tightened. For a more complete treatment of flange alignment issues, especially with regard to large diameter pipe, the reader is referred to the current version of ASME PCC-1, "Guidelines for Pressure Boundary Bolted Flange Joint Assembly", Appendix E.

<u>Fastener-related installation issues</u>

<u>Specifications and condition</u>
As with the flanges all of the bolts, nuts and washers must be verified for proper size, grade markings and should be inspected for any rust, corrosion, or thread damage issues. Since 2013, AWWA C207 allows only ASTM A193 grade B7 studs, ASTM A194 grade 2H nuts and the equivalent of ASTM F436 hardened washers to be used. Nuts should be free running on the bolt threads and care should be taken to ensure that they are installed with the markings facing away from the flange and not upside down. The washer too will generally be chamfered with the markings, if there are any, stamped on that chamfered side which should face away from the flange. It is a good practice to have the all of the markings for the studs or bolts ("B7" will be stamped on one end only), nuts and washers facing outward and visible from the tightening or "working" side of the joint for inspection purposes. Bolts should be long enough to fully engage the threads of both nuts through the flange when installed before tightening. Any excess length should be adjusted to one side, usually the "back side" of the flange away from the "working" side so that a socket can fully engage the nut for tightening. The bolt should be at least flush with the top of the nut on the working side after tightening but it is acceptable and common practices to leave 1-3 threads showing for inspection purposes.

The use of hardened washers is recommended for three important reasons. First, the increased surface area under the nut tends to spread the bolt load improving the stiffness of the joint. Second, the washer protects embedment or damage to the flange surface as the nut is turned down and third, the hardened washer provides a surface with more consistent coefficient of friction for the nut to turn on. This ensures a more uniform torque and therefore uniform bolt load around the joint. Softer washers must not be used as they will provide none of these benefits and may contribute to bolt load loss over time as they are compressed.

Gasket-related installation issues

Specifications and condition

The principle governing document for the selection of water joint gaskets is AWWA C207(2013). Table 1 from AWWA C207 is shown below.

Table 1 - Flange gasket materials, type and thickness

Flange Class	Working Pressure		Nominal Pipe Diameter				Thickness	
	psi	(kPa)	in.	(mm)	Material	Type	in.	(mm)
B	86	(593)	4-24	100-600)	Rubber, CFG, PTFE	Full Face or Ring[1]	1/16	(1.59)
B	86	(593)	26-144	(650-3,600)	Rubber, CFG, PTFE	Ring[1]	1/8	(3.18)
D	175	(1,207)	4-12	(100-300)	Rubber, CFG, PTFE	Full Face or Ring[1]	1/16	(1.59)
D	150	(1,034)	14-24	(350-600)	Rubber, CFG, PTFE	Full Face or Ring[1]	1/8	(3.18)
D	150	(1,034)	26-144	(650-3,600)	Rubber, CFG, PTFE	Ring[1,2]	1/8	(3.18)
E	175	(1,207)	4-12	(100-300)	Rubber, CFG, PTFE	Ring[1,2]	1/16	(1.59)
E	150	(1,034)	14-24	(350-600)	Rubber, CFG, PTFE	Ring[1,2]	1/16	(1.59)
E	275	(1,896)	4-24	(100-600)	CFG, PTFE	Ring[2]	1/16	(1.59)
E	275	(1,896)	26-144	(650-3,600)	CFG, PTFE	Ring[2]	1/8	(3.18)
F	300	(2,068)	4-24	(100-600)	CFG, PTFE	Ring[2]	1/16	(1.59)
F	300	(2,068)	26-48	(650-1,200)	CFG, PTFE	Ring[2]	1/8	(3.18)

*Maximum pressure (test or transient) is provided in Tables 2 through 5.

NOTES:
1. Care must be taken with ring gaskets to prevent over compressing the rubber.
2. To accommodate insulation/isolation requirements, full-face gaskets are allowed for Class B and D flanges larger than 24 in., and for Class E and F flanges. When using full-face gaskets, bolt torque will need to be increased substantially to achieve adequate gasket seating pressure.

As can be seen in the above table, the standard allows only the use of rubber, compressed fiber sheet, or Polytetrafluoroethylene (PTFE) gaskets generally as interchangeable options in most water flange joints. While the installer is usually not involved in the selection of the gasket material it is important that he verify that the supplied gaskets match the engineer’s specifications for material, size, thickness and compressibility or hardness. Check to make sure that what was specified is what was delivered. When in doubt, check with the project engineer.

As a broad generalization rubber gaskets are typically used where pressures are <150 psi. The most common type of rubber used in water pipe joints is styrene butadiene rubber (SBR) commonly referred to as “red rubber”. Although in recent years many utilities have begun using ethylene propylene diene monomer (EPDM) gaskets which may be used to 175 psi pressures because of their higher durometer (hardness) and compression set (load retention) capabilities. EPDM is also approved under the NSF/ANSI-61 standard for potable water systems. Ensure that these higher standards and materials are used when dealing with drinking water systems.

Generally for Classes E and F (above 175 psi) non-asbestos compressed fiber is the gasket material of choice. These gaskets consist of typically aramid fibers suspended in a rubber binder. They compress less, have much higher tensile strength and resist gasket creep better than homogenous rubber. Some recent formulations include what are called “controlled swell” characteristics where the gasket actually expands when exposed to water counteracting the effects of gasket creep and other load loss factors. Installation procedures including torque and gasket stress goals may need to be adjusted accordingly.

Finally, Teflon® (PTFE) gaskets may be specified where extreme purity requirements such as the NSF/ANSI-61 standard must be met in higher pressure systems.

The gasket must match the dimensions of the flange and should contact the entire sealing surface. For full face gaskets, the bolts pass through the gasket. Ring gaskets sit inside the bolt circle and are centered by the bolts. Adhesives should not be necessary to hold the gasket in place during installation since the bolts will provide that support. Check with the gasket manufacturer before using any adhesive or release agent to ensure that it will be compatible with the gasket material. Greases should not be applied to the gasket or flanges surfaces as they may create a leak path and they may react adversely with the gasket material.

All gaskets suffer permanent deformation when installed in a joint. NO RE-USE OF GASKETS once they have been tightened should ever be considered.

Gasket creep

This is a phenomenon that deserves special attention. It is also called “creep relaxation” or “cold flow” and it is a major cause of bolt load loss and resulting leaks in joints with soft gaskets. When soft gasket materials are first put under load they initially resist compression. However within a few minutes to a few hours under load they tend to flow away from the pressure, permanently thinning and causing a corresponding drop in the bolt load. Each type of gasket has its own “creep factor” or percentage of load loss. Consult the gasket manufacturer’s literature or consult directly with their technical service representatives to determine these values. They may be as much as 20-50% of gasket thickness depending upon the material. Creep generally happens within the first 4-6 hours after assembly. It generally does not repeat, because the gasket material reaches a stable density and resists further thinning. Retightening of the bolts to the same original torque value must be done at some point after install to account for creep, but the re-torqueing should wait at least 4 hours after the original install. If that is not possible, then controlled tightening to the upper limit of the recommended gasket stress range must be done so that even after the creep relaxation effect, there will still be sufficient gasket load to maintain a seal.

Tightening-related installation issues

Gasket stress
Although calculating the appropriate gasket stress is not directly the responsibility of the installation crew it is important that everyone who tightens a flange understands the definitions of, and the relationship among applied torque, achieved bolt load, and the resulting gasket stress.

Torque is a turning force applied in this case to a bolt or a nut. In common bolting language it is the product of the amount of applied force in pounds (or in Newtons or kilograms in metric terms) multiplied by the distance in feet (or meters) over which the force is applied. It is commonly expressed as foot-pounds (or as Newton-meters or Kilogram-meters). The correct amount of torque to apply to a given fastener is subject to a number of factors including the diameter and grade of the bolt, the thread pitch, the desired amount of tension in the bolt, and the friction coefficient of any lubricant. Torque is not a desired end, but a means to create and estimated bolt load. (ASME PCC-1 Appendices J and K for a more complete discussion of the torque-load relationship). Torque alone has no meaning without taking these variables into consideration.

Bolt load is the resulting clamping force that is created by turning a threaded fastener and stretching the bolt. It is expressed in pounds (or in kilo-Newtons or metric tons). Bolt tension is the bolt load divided by the cross-sectional area of the bolt and is expressed in pounds per square inch (psi) or often in thousands of psi (ksi), or (mega-Pascals in the metric system). The sum of the bolt-loads in the flange is the total load in the joint.

Gasket stress is the total joint load divided by the square inches (or square millimeters) of gasket contact area under compression inside the joint. Each gasket has a published range of acceptable gasket stress between its minimum sealing stress and its maximum gasket crush stress. Achieving a gasket stress level within the acceptable sealing range is the goal. Bolt-loads, and torque values are adjusted to accomplish that end.

Bolting patterns and sequences
If all bolts were isolated then independent bolting would be a relatively simple matter. But as a matter of fact in most joints, especially including gasketed pressure joints, what is done to one bolt will have an immediate and significant effect on the retained load in the others in that connection. This elastic interaction between bolts is referred to as “crosstalk”. If a bolt in a joint is tightened to a specified torque or load and then the bolts on either side are tightened to the same value, the load in the first bolt will unavoidably be reduced as its tension is shared by its neighbors. Minimizing the crosstalk and achieving a final parity is important with three goals in mind:

1. Gradually increasing load
   Unlike steel bolts and steel flanges which are elastic like springs, gaskets are by definition deformable and generally non-elastic. [Rubber gaskets will indeed spring back if compression is reduced but only in the short-term. Rubber under long-term pressure will be permanently thinned in the area under load]. As the joint is drawn together it is important to minimize any decompression of the gasket because once compressed it will

not spring back into its original thickness forming a seal. Bolts must be tightened in gradually increasing steps in an effort to only increase, never decrease load on the gasket.

2. Parallel closure
   To minimize both bolt crosstalk and other uneven loading of the gasket, bolts must be tightened in a pre-determined crisscross pattern or by simultaneous tightening with multiple wrenches. The goal is to avoid any cocking of the flanges during tightening that might cause damage to the gasket. Bolts are tightened in an alternating pattern designed to keep the flanges parallel as they are drawn together. (See ASME PCC-1 Table 2 and Appendix F for acceptable tightening patterns which also apply to AWWA flanges).

3. Uniformity of bolt-load
   The goal is to end up with all bolts as near equally tight as possible. After all the bolts have been tightened to the desired load in their pattern sequence, it is necessary to conduct a "check-pass", usually done in a circular manner bolt by bolt at the final torque value until no additional turning can be noted in the nuts.

As previously discussed, a retorque of the bolts at least 4 hours after initial tightening is almost always necessary to compensate for any relaxation due to gasket creep. This re-torque is normally done in the same circular manner as the "check-pass", at the same final torque value. See Table 2 below for tightening requirements.

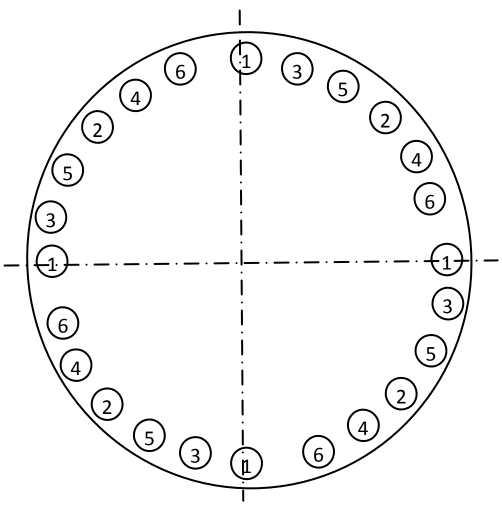
Table 2 – Torque Increments for Legacy Cross-Pattern Tightening Using a Single Tool

Step	Loading
Install	Hand tighten, then "snug up" to 15 N·m (10 ft-lb) to 30 N·m (20 ft-lb) (not to exceed 20% of Target Torque). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening before proceeding.
Round 1	Tighten to 20% to 30% of Target Torque (see section 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening/loosening before proceeding.
Round 2	Tighten to 50% to 70% of Target Torque (see section 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening/loosening before proceeding.
Round 3	Tighten to 100% of Target Torque (see section 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening/loosening before proceeding.
Round 4	Continue tightening the bolts, but on a circular clockwise pattern until no further nut rotation occurs at the Round 3 Target Torque value. For indicator bolting, tighten bolts until the indicator rod retraction readings for all bolts are within the specified range.
Round 5	Time permitting, wait a minimum of 4 hr and repeat Round 4; this will restore the short-term creep relaxation/embedment losses. If the flange is subjected to a subsequent test pressure higher than its rating, it may be desirable to repeat this round after the test is completed.

Simultaneous Use Of Multiple Tools

A better way to achieve the goals of gradually increasing load, parallel closure, and bolt load uniformity is the use of multiple tightening tools used simultaneously around the joint. This is normally done with hydraulic torque wrenches, usually 4 at a time, connected to a single pump with common pressure and therefore common torque. By placing the wrenches opposite one another around the joint the flanges can be drawn together parallel each other and with equal bolt loads all around. One tool per every 4 to 8 bolts is the norm. Not only is the final result more uniform but there is much less chance of localized gasket crushing and the bolting time is typically reduced by 50 to 75%. (See ASME PCC-1 Appendix F, Alternative Pattern #4)

24 BOLT FLANGE
4 TOOLS AT ONCE



Group Numbering

Number the flange with the bolt sequence groups corresponding to the number of bolts in the flange and the number of tools employed *(for this example assume a 24 bolt flange, with 4 tools being used to tighten).*

- Mark the bolts at the 12, 3, 6, and 9 o'clock positions with the number 1
- Moving clockwise split the 90º angles between the marked of their own number bolts and number the next group as number 2.
- Split the remaining large angles as evenly as you can and continue numbering the groups until all bolts are numbered. All bolts are now numbered in groups at 90 degrees from each other.

Tightening
Tightening is accomplished in 3 incremental passes

Pass #1- Tighten approximately ¼ of the bolts to 50% of the target torque. In this example tighten all of the 1's and then all of the 2's to 50% of the target torque. It is not necessary to do the remaining bolts because the purpose of this initial pass is to seat the gasket and square up the flange. Flange alignment and gap should be checked. The remaining nuts will have loosened so valuable time can be saved at this point by snugging them again.

Pass #2- Tighten all of the bolts to 100% of the target torque beginning with the 3's then 4's then 5's then 6's then returning to the 1's then 2's

Pass #3 (check pass)- Beginning from the end of the previous pass and with the torque value still set at 100% of the target, move the tools clockwise one bolt at a time until no movement can be gotten out of any nut. This is the check pass that compensates for elastic interaction and brings all bolts into parity.

This same three-pass procedure is used regardless of the number of tools. The only exception would be 100% coverage where tightening is done in one pass.

Troubleshooting and Problem Solving

Following proper assembly techniques should result in a leak-free joint in the vast majority of cases. Leak-free service should be expected every time, not just as an exception. But occasionally things do go wrong and knowing where to look for the causes and what to do to quickly correct the problems is imperative. As previously noted one of the valuable resources on flange bolting is the ASME PCC-1-2013 "Guidelines for Pressure Boundary Bolted Flange Joint Assembly". While not all of the material in this standard applies to the low pressure water pipe joints, Appendix P of that document, particularly table P-1, contains valuable suggestions for about what is might be causing a leak and what to do about it.

Personnel Training

While nothing can replace on-the-job experience, relying on trial-and-error or on informal word-of-mouth pass along hints from one employee to another is not the best way to improve performance. Fortunately there are new training options available for bolting assembly personnel. One of the most useful and comprehensive of these courses is OSHA Training Institute Course #7110, "Safe Bolting: Principles and Practices", offered through the Texas Engineering Extension Service (TEEX), a unit of Texas A&M University and other authorized OSHA Training Centers. This one-day on-site practical course reviews the joint assembly principles discussed in this paper coupled with hands on instruction on bolting tooling and safety procedures.

Unique Situations

This paper discusses many common flange field installation problems that may occur. There are also unique situations that require special considerations on a project by project occurrence. Usually these exceptions to the normal procedures happen due to design problems or unique situations such as the use of non-standard materials or non-specification flanges. A qualified flange design engineer should be consulted on such projects to assist with the proper field solutions. Two recent examples of unique design decisions are briefly reviewed below:

1. Large diameter (14') flange joint on a penstock with a thinner flange than would be required by AAWA or ASME rules for the 220 psi design internal pressure. This flange, with an elastomer "O" ring gasket leaked when first installed. The final solution was to stiffen the flange by utilizing oversized, thick washers to allow for the added flexibility of longer bolts and greater torque values on each bolt. A critical aspect of this fix was to follow a unique assembly process involving the use of PCC-1 principles together with bolt load- torque calibration approach to minimize load scatter to $\pm$ 10%. This was accomplished by using four indicator bolts to relate a desired bolt "stretch" (and the corresponding target load) to a specific torque. That torque was then applied to all 60 bolts in a circular pattern. The solution worked.
2. HDPE plastic flange leak. HDPE plastic flanges will "cold flow", or creep, away from a source of stress that is higher than that which the material can support over time. Unpublished bolt load relaxation calculations were done. These indicated that torques consistent with steel pipe would lose 40% of the applied load within 12 hours. Further creep loss would have occurred over a longer time period, until the face pressure had

reduced significantly. The vendor and the Plastic Pipe Institute recommended torque values that were much lower but essentially consistent with the "relaxed" bolt load for the project for the 54 in. diameter, 44 bolt joints. On this project the gaskets were not seated at this low torque level and several "blow-outs" occurred during hydrotest. As a fix, torque levels around 6 times higher were recommended for these joints to assure proper seating. In addition, for configurations with thick plastic flanges, Bellville spring washers were recommended to compensate for the creep load loss. It is important to recognize the differences in assembling steel flanges as opposed to plastic flanges. Somewhat reduced torque values may be utilized on the plastic flanges but re-tightening them after a proper time lapse to account for the cold flow of the material is essential.

Summary

Bolted flange joints can be a reliable part of water piping systems when properly designed and assembled. Long experience has proven the effectiveness of standard flanges constructed according to AWWA C207 and related specifications. Leakage from these standard joints is usually due to problems with their assembly, not with their design. Guidance to help installers, inspectors and engineers avoid these field problems can be found in AWWA C207 (2013), AWWA M11 (2004) and ASME PCC-1-2013 which provide detailed flange specifications and assembly guidelines. Formal training of assembly personnel can have a major positive impact on the success of these bolted connections. Properly assembled and tightened joints do not leak, leaks should be the exception and not the rule!

References

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