The New Interactive AWWA M11—Flange Bolt Torque Calculator—A Technical Guide to Its Background, Relevance, and Use

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ABSTRACT

The sequence of tightening bolts and controlling torque are very important to the assembly of flanged pipe joint connections. Among other factors, proper-flanged joint closure depends on applying the correct amount of gasket load and achieving uniform load around the joint. Since the load applied to the joint by the bolts is difficult to measure directly, torque is used as a convenient way to approximate the desired load. This paper will review torque calculations as they apply to ANSI/AWWA C207 flanges and the new AWWA web-based interactive tool, including examples for torque calculations as described in the recently published, *AWWA Manual M11, Steel Pipe—A Guide for Design and Installation, 5th Edition.*

BACKGROUND

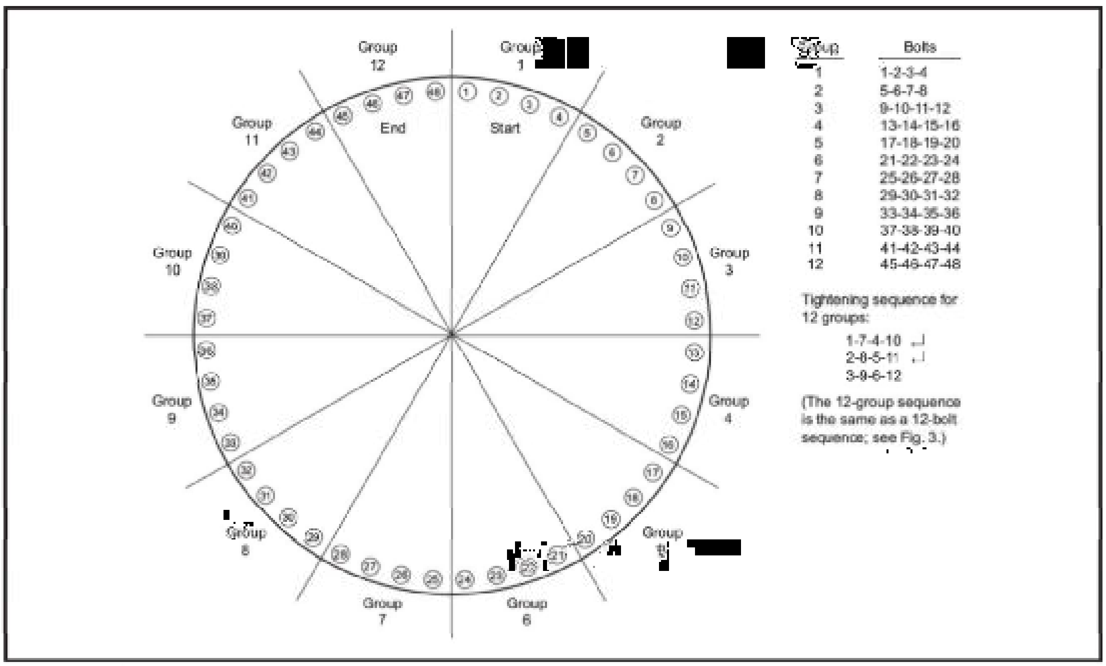
The success of flanged joints depends on applying the correct amount of gasket load and achieving uniform load around the joint. ANSI/AWWA C207 (2018) states requirements for flange facing, gasket material, and bolting material. Flanges are to be flat faced, without projection or raised face with a serrated concentric or spiral finish with a resultant finish of 125- to 500-µin. roughness. Gasket material may be either rubber, compressed fiber or PTFE (polytetrafluoroethylene). Bolting material shall be ASTM A193 grade B7 with ASTM A194 grade 2H heavy hex nuts for bolts larger than 1 in. and ASTM A 563 heavy hex nuts for bolts 1 in. and smaller.

GASKET LOAD

AWWA M11 (2017a) states that gaskets seal joints as they are compressed to fill imperfections and spaces in the flange faces. Insufficient compression can result in imperfections and spaces not being filled and can also result in insufficient resistance to hydrostatic pressure. Excessive compression can result in pinching or crushing of the gasket and consequently possible leakage. Desirable gasket load is generated by tightening the bolts in a controlled and uniform manner, usually to a given percent of their yield. By convention and design, most bolting of gasketed flanges is carried out to achieve a stress of approximately 50 percent of bolt material yield strength. The sum of all the bolt loads in the joint divided by the contact area of the gasket with the flanges equals the gasket stress.

BOLT LOAD

AWWA M11 (2017a) states that it is the bolt load that compresses the gasket and seals the joint. However, it is not just how tight the bolts are, but also how consistently they are loaded that ensures a proper seal. The intent is not just to achieve a sufficient load but also to minimize variations among the bolts. A complication to achieving uniform tightness is that bolts act like interactive springs in the joint. Tightening any one bolt will change the effective load of the nearby bolts. No matter how accurately torque or tension is initially applied to any single bolt, a subsequent retightening of all the bolts must be done to even out the load. A further complication is that although bolts react quickly and completely as loads shift during tightening, soft gasket materials do not exhibit similar resilience. Care must be taken to not overcompress the gasket because it may not spring back to fill the void if the load under any one bolt is reduced. That is the reason for gradually increasing the pressure in stages to the final load. In order to even out these loads, bolts are tightened in a specific sequence using gradually increasing passes or steps to achieve the final tightness.



GENERAL NOTE: This figure is an illustration of how bolts may be grouped for tightening. Bolts maybe grouped and tightened treating these groups as one bolt in the tightening sequence. A suggested number of bolts for a group is the number contained within a 30 deg. arc. However, potential gasket damage or flange misalignment should be considered when bolts are grouped.

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Figure A.1 Legacy Pattern—48-bolt flange bolt grouping example

Fig. 1 Bolt Tightening Pattern From ANSI/AWWA 604 (2017b)

ANSI/AWWA C604 (2017b) provides guidance on various tightening patterns that can be used. Fig. 1 is an example of one of these patterns. Whatever pattern is chosen, it should accomplish several interrelated goals to

- Apply sufficient bolt stress to maintain a leak-free connection
- Achieve uniform bolt stress and therefore uniform gasket stress around the flange

- Maintain parallel closure of the flanges during tightening
- Minimize excessive loading/unloading of the gasket during tightening
- Avoid overcompression or crushing of the gasket
- Reduce tool movements to improve efficiency
- Be simple to implement for the assemblers

Since the load applied to the joint by the bolts is difficult to measure directly, torque is used as a convenient way to approximate the desired load. Load is achieved by a controlled turning force (torque) applied to the bolt head or nut. Torque is the product of a force times the distance over which it is applied. Torque is developed by the turning of threaded nuts and bolts that require surfaces to slide past one another. To accurately convert torque into load, the friction that exists between the sliding surfaces must be known. Friction is reduced by the application of a lubricant. It may take three times the torque to achieve the same bolt load with a dry fastener as with one that has been lubricated.

Nut-and-bolt assemblies have two sliding surfaces: (1) the mating threads and (2) the face of the nut where it contacts the flange. Therefore, the amount of force necessary to tighten a nut/bolt to any given load value depends on the friction between the two surfaces.

The relationship between torque and load in this context may be expressed by the following formula cited in ASME PCC-1, appendix J (2013a):

$$T = F\left[0.16p + 0.58\mu_t d_2 + \frac{D_e \mu_n}{2}\right]$$

Torque to Stretch the Bolt	*Torque to Overcome Thread Friction*	*Torque to Overcome Face Friction*

Where:
T = total tightening torque, ft-lb
F = bolt preload, lb
μ_t = coefficient of friction for the threads
n = number of threads per in.
d_1 = thread major diameter, in.
d_2 = basic pitch diameter of the thread, in (for inch threads $d_2 = d_1 - 0.6495/n$)
p = pitch of the thread; normally threads/ inch, i.e., $p = 1/n$
μ_n = coefficient of friction for the nut face or bolt head
D_e = effective bearing diameter of the nut, in. = $(d_o + d_i)/2$
D_o = outer bearing diameter of the nut, in.
D_i = inner bearing diameter of the nut face, in.

Notice in the above formula that the applied torque has to overcome three resistant forces: bolt stretch, thread friction, and face friction.

To simplify this calculation, a formula that combines these three resisting forces into a single variable, K, referred to as a "nut factor" when used in the following simplified torque/load formula cited in ASME PCC-1, appendix K (2013a).

$$T = \frac{(K \times D_s \times F)}{12}$$

Where:
T = torque—the turning force required, ft-lb

K = nut factor—how hard it is to turn, expressed as a decimal
D_s = nominal diameter of the stud, in.
F = load desired in the stud, lb

K is an empirical value related to the total resistance, derived experimentally by applying tightening torque to a bolt of a given nominal diameter in a scale device and observing the resultant load.

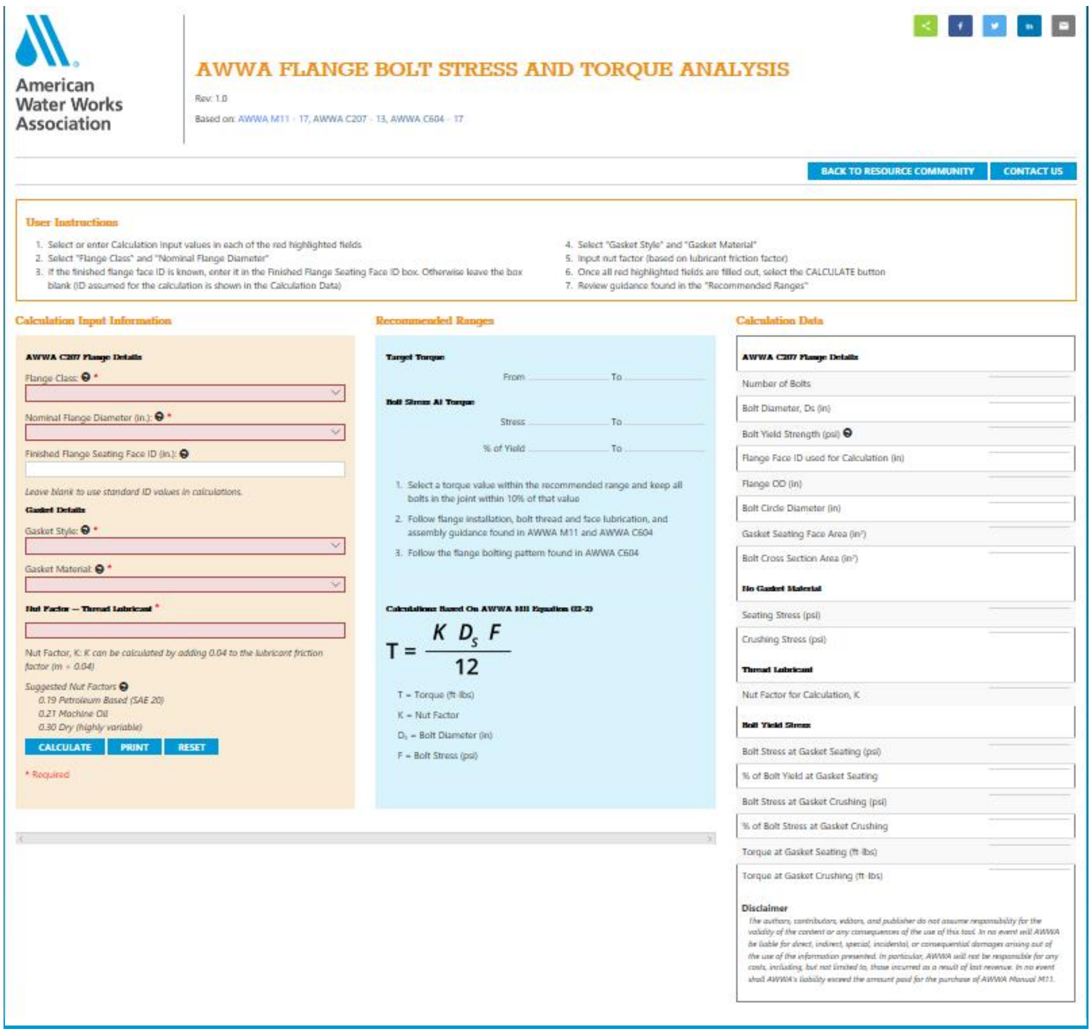

Fig 2. AWWA Interactive Torque Calculation Tool (2017c)

K is dependent on a number of factors such as temperature, quantity and application of lubricant to sliding surfaces, bolt diameter, thread pitch, fastener condition, and the applied load. Experience has shown the use of a nut factor to be for all intents and purposes as reliable and accurate as the more complex torque formula, and it can be relied on to produce acceptable results if consistently applied. Once determined, it is then applied generally to bolts of the same grade and diameter to relate torque to load. At normal assembly temperatures with standard bolts, the derivation of *K* can be simplified by adding 0.04 to the lubricant's coefficient of friction, μ (Bickford 1995). Coating or plating of bolts will also result in different friction conditions and therefore different torque requirements that for uncoated fasteners.

SUGGESTED VALUES FOR *K*

AWWA M11 (2017a) states that tests conducted by Brown et al. (2006) showed that average *K* values for a number of copper-, nickel-, molybdenum-, and graphite-based antiseize lubricants on standard ASTM A193 grade B7 studs were in a fairly consistent range from 0.16 to 0.18, regardless of assembly temperatures ranging from 23ºF to 105ºF. Consensus figures from multiple sources place the *K* value for petroleum-based lubricants such as SAE 20 oil at approximately 0.19 and for machine oil at approximately 0.21. Although dry alloy steel exhibit a rather wide scatter of values, a *K* value of 0.30 has been successfully used.

Testing by Cooper and Heartwell (2011) demonstrated that the presence of a through-hardened washer under the nut or bolt head has as great a positive effect on reducing overall friction as the use of a lubricant. The conclusion being that a hardened washer should be used under all turning nuts both to reduce required torque and also to improve consistency of load among the bolts.

TORQUE CALCULATIONS:

The recently published, AWWA Manual M11, Steel Pipe-A Guide for Design and Installation, 5th Edition (2017a) included a reference to an AWWA web-based interactive tool to do the torque calculations based on user input. The interactive tool can be found at www.awwa.org/TorqueCalc. A screen shot view is shown in Fig. 2.

The Torque Calculation Tool includes the following User Instructions:

1. Select or enter Calculation Input values in each of the red highlighted fields
2. Select “Flange Class” and “Nominal Flange Diameter”
3. If the finished flange face ID is known, enter it in the Finished Seating Face ID box. Otherwise leave the box blank (ID assumed for the calculation is shown in the Calculation Data)
4. Select “Gasket Style” and “Gasket Material”
5. Input nut factor (based on lubricant friction factor)
6. Once all red highlighted fields are filled out, select the CALCULATE button
7. Review guidance found in the “Recommended Ranges”

The user is able to select from ANSI/AWWA C207 (2013b) flange classes, gasket materials, and flange diameters. Based on the users input, the torque calculator generates a recommended torque range to select the appropriate torque value for the application. It also offers warning to the user if they have a potential of either crushing the gasket with too high of a load or not getting enough load to seat the gasket with their selected inputs.

CONCLUSION

A successful flange installation requires the proper amount of load applied to the gasket. The conventional way to achieve that load is by applying a measured torque to the flange bolts. The recently published, AWWA Manual M11 includes a description of calculating torque values for bolting ANSI/AWWA C207 flanges including the addition of a web-based, interactive tool for completing the torque calculation. The interactive tool provides users a way to easily determine an appropriate torque for their AWWA C207 flange installation.

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