Pre-Load A Primer

by Laurence Claus

In the world of fastener engineering, all too often the joint designer gets focused on the wrong things; torque, locking mechanisms, degrees of rotation, and a number of other sundry items, at the expense of focusing on the most important element, joint tension. Of course, this is understandable since torque and angle are the fundamental measures the industry uses in tightening critical joints. Additionally, torque and angle are easily measured and reasonably easily controlled. However, it is the tension that holds the joint together, which makes it supremely important both at installation and over the service life of the joint. Therefore, it is critical that the joint designer generates sufficient tension so that the joint can perform safely immediately after tightening, but also years down the road after relaxation and other diminishing effects have acted on the joint.

Like other complex or even simple systems, engineers have developed a set of commonly used terms to describe what is happening. When tightening a joint and generating tension, the term that has been assigned to describe this is "pre-load". Pre-load defines the axial load generated in the bolt member. This axial load compresses the joint together bringing rise to another commonly used term, clamp load. The clamp load is generally considered the compressive load that is pulling or clamping the entire joint together. The pre-load and clamp load, therefore, share a direct and symbiotic relationship to one another.

With those basic concepts in-hand, one might inquire why pre-load is important? The simplest answer is derived from a universally accepted fastener engineering rule-of-thumb, that a properly tensioned joint will seldom come loose. But what does this mean from a practical standpoint? Consider this illustration to answer that question. Place your thumb, index, and middle fingers together as illustrated in **Figure 1.** Now take and wrap a standard heavy duty rubber band twice around these fingers or until the rubber band is snug but not blood circulation stopping tight as in **Figure 1**. Now separate your fingers and observe the level of resistance to your effort to separate them as shown in **Figure 2**. Once you have completed this exercise make one additional wrap of the rubber band as shown in **Figure 3**. Again attempt to separate your fingers and observe the effort required to perform this action.


Figure 1

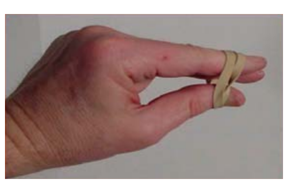
Figure 2


Figure 3

If you have conducted this exercise properly, you should have clearly observed that the effort required to separate your fingers with the third wrap of rubber band in-place is sufficiently greater than the first scenario with only two wraps. The same is true for a bolted joint. The more pre-load that is generated in the joint, the more difficult it becomes to separate or break the joint loose. This behavior is true whether the joint is a tension joint (where the service load is trying to pull the joint apart) or a friction-slip joint (where joint tension generates friction between the clamped surfaces so that they cannot move relative to one another.)

So how does one go about getting a bolt or screw to generate a pre-load? Consider that the bolt is really a very stiff spring. For many this concept is counterintuitive, as it is very difficult to envision, for example, a ¾" (M19) bolt actually being displaced like a small coil spring. That, however, is exactly what happens. In the same way that a coil spring stretches or compresses to create tension, so a bolt must stretch to provide pre-load. Like the rubber band illustration above, the more the bolt is stretched the higher the achieved pre-load.

To further understand this behavior, one must understand the fundamental behavior of steel. It is important to realize that this "stretching behavior" is not infinite. As you pull on steel bolts there is a region under their stress-strain curve, known as the elastic zone, where the bolt will stretch in a linear fashion relative to the load. This means that in this zone you can apply a load and stretch the bolt, but as soon as you release the load the bolt will return to its original length. However, at some point, the stress-strain behavior transitions from linear to non-linear behavior. Once this occurs, if the load is released the bolt will not regain its original length, but rather be stretched out longer. This non-linear zone is known as the plastic zone. The transition point between these two is most commonly referred to as the yield point. If the bolt is stretched beyond this point, not only will permanent set occur, but ultimately the bolt will fail by breaking. This is the point known as the ultimate strength or ultimate tensile strength.

Understanding this behavior explains why the Fastener Engineer may choose a high strength bolt for critical joints. As a bolt increases in strength (has a higher Property Class or Strength Grade) the level at which it will begin to yield also goes up. Practically speaking, this means that a higher strength fastener has a greater capacity to generate pre-load. **Figure 4** shows comparative stress-strain behavior of typical low, medium, and high strength fasteners. As is clearly illustrated, the higher strength fastener will have a greater capacity to generate pre-load. However, as is also evident from this illustration, the higher the fastener strength the lower the degree of plastic deformation prior to reaching the ultimate strength. In most cases, however, this should be of minor consequence as most fastener engineers do not wish to tighten joints so that they risk taking the bolt to yield or beyond.

The importance of pre-load really becomes the tool of the fastener engineer. As mentioned at the beginning of this article, a properly tensioned joint rarely fails. Therefore, the fastener engineer must design their system in such a way as to guarantee that the pre-load exceeds the service loading that the joint feels or potentially will experience in its service lifetime. To gain a better understanding of this, consider **Figure 5** which illustrates this concept. Illustrated at position #1 is a spring with a hook on the end. At position #2 a 1,000 lb. weight is hung from the hook. Naturally the weight causes the spring to deflect a certain distance. In position #3 a block is placed between the hook and the spring to "lock" this displacement in-place. The weight can be removed and the system remains as it was in this deflected (or pre-loaded) state. In Position #4 a two hundred pound weight is hung from the hook. As expected, nothing will happen because this load is insufficient to further deflect the pre-loaded state of the spring. However, if a 1,001 lb. weight is placed on the hook as illustrated in position # 5, the spring will deflect further and the block will fall out.

A bolted joint is analogous to this illustration. As long as the pre-load in the bolt exceeds the service loads being exerted on the joint, the joint will remain intact. However as soon as the service loading exceeds the pre-load the integrity of the joint no longer exists. Achieving the desired pre-load is subject to a variety of different strategies and methods. The merits of each method rest, to some degree, on the variables of each specific joint and the practices and conventions of the industries employing them. A discussion of these principles and methods should be reserved for another article. However, it is clear that regardless of the practice used, achieving the desired pre-load is the real critical challenge. Fastener engineers must always keep this at the forefront and not lose sight of this goal at the expense of focusing on other criteria.

Figure 4

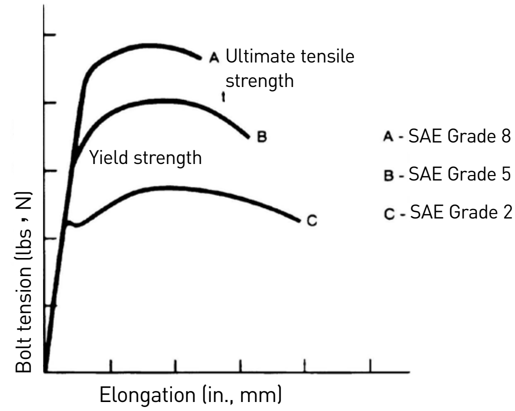

Figure 5