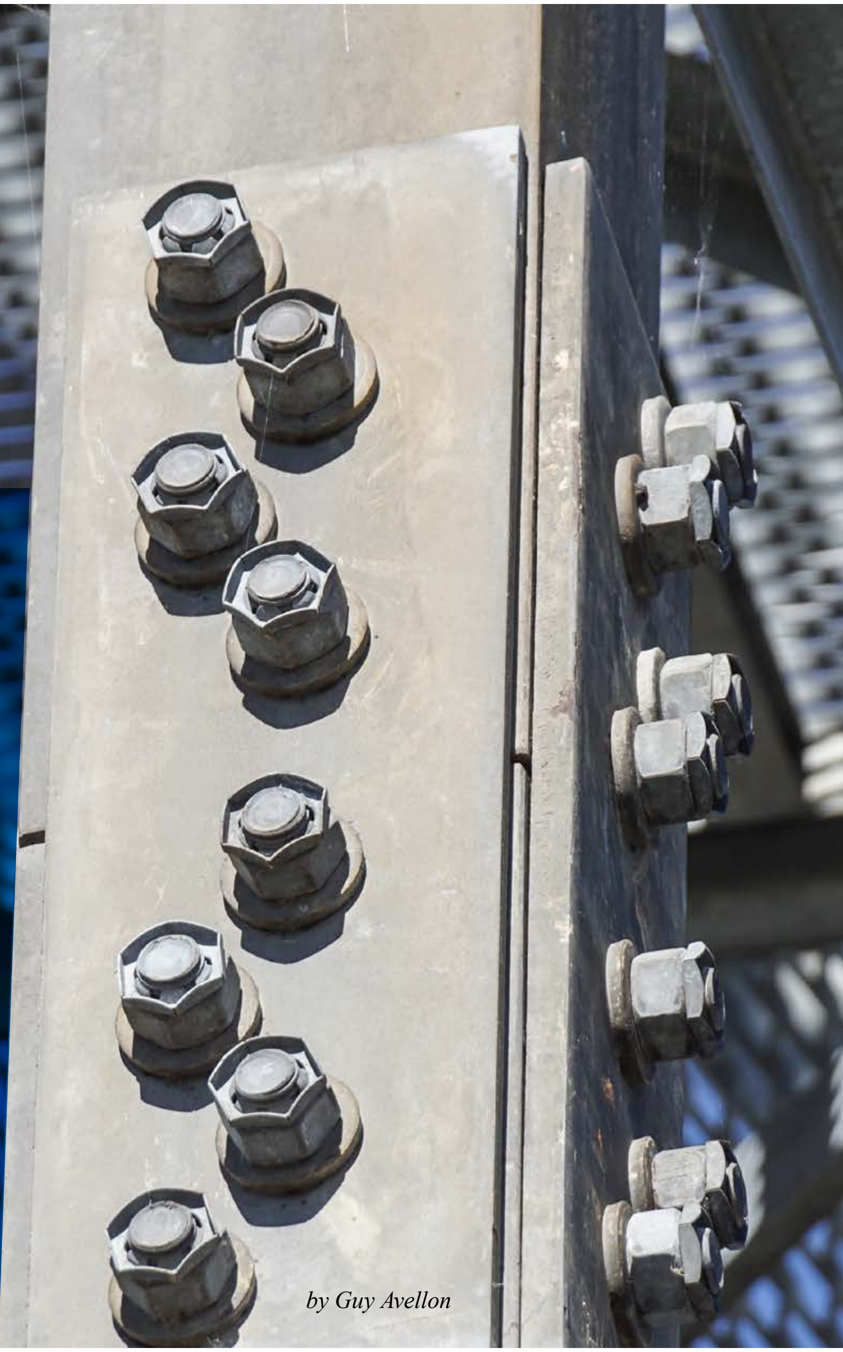
How To Determine the Strength of a Joint



by Guy Avellon

The modulus of elasticity will determine the relative stiffness of the joint members and the bolts used to produce the clamp load. The stiffness of each will determine how much clamp force is necessary, what size of bolts to use and how the clamp loads will change when the service loads act upon the joint.

All metal components behave like springs. The relative response to stress under loading is governed by the comparative stiffness of each component. If the spring rate of the bolt is equal to the combined spring rate of the joint, then half the deformation will occur in the bolt and the rest will be absorbed by the joint.

Clamping force exerted by the bolt on the joint is produced by an equal and opposite force by the joint onto the bolt. All things being elastic, the bolt wants to return to its original length while the joint also wants to return to its original thickness.

To illustrate this, a Force Diagram **(Fig. 1)** is used which is a stress-strain diagram with elastic curves for both the bolt and joint member.

As the bolt is tightened, the bolt elongates (ΔB). Due to the natural internal forces resisting the elongation, a tension force or preload is produced (Fp). The applied force and elongation are linear. Since any action requires a reaction, the deformation of the joint is linear and is represented by ΔJ, the amount of joint compression.

Regardless of how soft the joint or bolt are, the bolt becomes longer and the joint becomes compressed under load when the bolt is tightened. Typically, the spring rate, or stiffness of the bolt is only 1/3-1/5 that of the joint.

The following diagrams illustrate the importance of the stiffness ratio between the bolt and the joint in determining how much of the applied external load is absorbed by the fastener and how much is absorbed by the joint.

Figure 2 illustrates a bolt and joint with approximately the same stiffness, as they are both absorbing an equal amount of the applied load F.

Figure 3 illustrates a softer or more springy fastener in a stiffer joint. The bolt has an increased strain and the joint is absorbing the greater amount of the load F.

Figure 1. Force Diagram

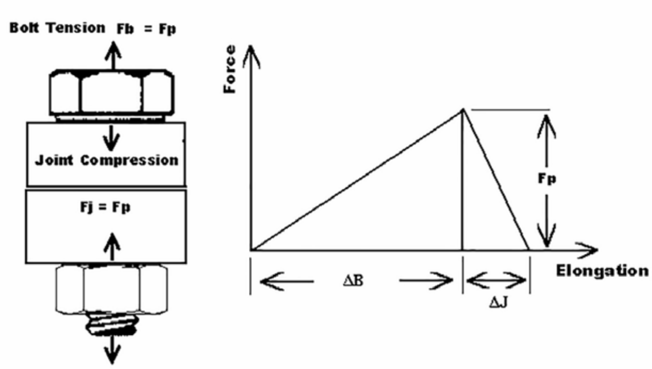


Figure 2. Stiffness Ratio Between the Bolt and the Joint

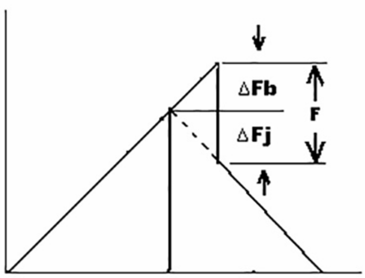


Figure 3. Softer or More Springy Fastener in a Stiffer Joint

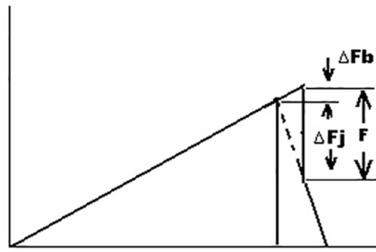
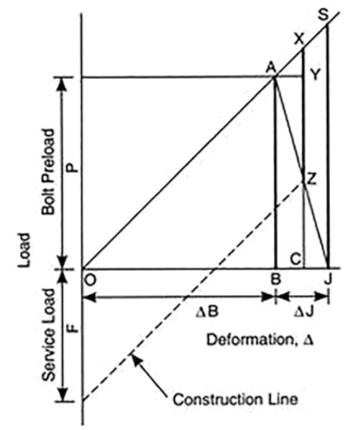


Figure 4. Static Service Load



If the bolt is less stiff, with respect to the joint, the bolt will experience a smaller percentage of the external load, which depends upon the stiffness ratio of the bolt and joint. This helps in determining what type and size of bolt to use in the joint. The stiffness ratio can also help determine preloads, loss due to embedment and bolt failure.

Other critical factors to consider are the hole size, surface finish of the contacting joint faces, flatness and the use of a washer.

In simple terms, the bolt does not experience the entire force of the external load. The vast majority of any additional load is absorbed by the clamped joint members because the joint is much softer than the bolt. In fact, it is five (5) times softer than the bolt. This is the reason why bolts tensioned at or near their yield point can often resist significant external loads. A good example are the head bolts on an engine.

At some point, the external load can be great enough to cause the clamp load to become completely unloaded. Any further additional load from this point will become entirely added to the tension of the existing bolt. The following **(Fig. 4)** is a joint diagram for a static service load.

Further completing the joint diagram under static load conditions, the initial bolt preload Fp is represented by the elastic load curve from O to A. The strain, or bolt deformation is ΔB, represented by O to B. The deformation of the joint is ΔJ, from J to B. The total joint load is S.

Any force change in the bolt, ΔFb, is represented by X-Y, which increases the strain from B to C. A construction line is drawn parallel to the slope of the strain of the bolt and is moved downwards to intersect the line Y-C at point Z. This is the load change in the joint, ΔFj, where ΔJ is the compression of the joint members and F is the service load.

Therefore, X-Y is the change in bolt load, ΔFb, and Y-Z represents the change in the joint load, ΔFj, which equals the service load.

As mentioned before, the bolt only experiences a portion of any external tension load on the joint. The amount of tension it sees depends upon the stiffness ratio between the bolt and the joint. It is the magnitude of the external load on the bolt that depends on the preload (Fp) of the bolt.

If the service load is cyclic and becomes greater than the preload, then conditions are set for vibrational loosening and / or metal fatigue.

The softest member of the joint will dominate the behavior of the joint. This is especially true if the softer member yields, which will limit the amount of force it will be able to support. Most joints will be solid but be aware of the effects of dissimilar materials and gasket joints.

For a given preload, a joint with more compliant fasteners will experience less variation in preload when the clamping members are compressed. The joint will have more of an equal distribution of axial loads in the fasteners when dynamically and cyclically loaded.

The fasteners with a shorter grip length and larger diameter will be able to absorb more axial loading when the clamped members are compressed. This means that the varying stiffness of multiple fasteners in a joint will have the fasteners that are more stiff than the others be more susceptible to overload in certain conditions.

Therefore, stiffness is a function of the shape of the body of the fastener as much as the material used. A longer bolt can experience greater strain than the shorter bolt and a smaller diameter bolt can have a longer fatigue life if the bolt is long.

The external tension load (Lx) required to produce a change of force and strain in the bolt and joint members is equal to the increase in force on the bolt (ΔFb) plus the reduction of force in the joint (ΔFj):

$Lx = \Delta Fb + \Delta Fj$

Bolt stiffness: $Kb = Fp/\Delta L$

Fp = tension in the bolt

ΔL = change in overall length of the bolt

Joint stiffness: $Kj = Fp/\Delta T$

ΔT = total joint thickness

Remember, all materials act as springs and the joint acts in parallel to the bolt. The amount of load each spring generates for a given displacement is proportional to the individual stiffness in each spring. Hooke's Law may also be applied to determine the amount of load lost or gained by joint displacement or relaxation.

Figure 5 Cyclic Service Loads