Over the last sixty years great improvements have been made by the fastener industry in improving the design and reliability of their products. However, no matter how well designed and made the fastener itself is, it cannot alone make the joint more reliable. Fastener selection, based upon an understanding of the mechanics of how a threaded fastener sustains loading and the influence that tightening procedures can play, is also needed. This article provides an introduction to the basics of bolted joints and the major factors involved in the design of such joints.

It is not widely understood how a bolted joint carries a direct load. A fully tightened bolt can survive in an application that an untightened, or loose bolt, would fail in a matter of seconds. When a load is applied to a joint containing a tightened bolt it does not sustain the full effect of the load but usually only a small part of it. This seems, at first sight, to be somewhat contrary to common sense but hopefully this article will explain why this is the case.

Bolts are made from elastic materials such as steel. When a bolt is tightened the bolt is stretched like a spring (figure 1). The joint itself is usually made of a metallic material which is also elastic. As the bolt is tightened, the joint is compressed and acts as a compressive spring (figure 2).

Put together, the bolt and the joint act as a combined spring system. In a tightened joint, the tension force in the bolt is balanced by the compressive force in the joint (figure 3). A key point to understanding how forces are transferred in a bolted joint is to realise that the only way that the bolt can be loaded is by applying a load through the joint.

Loading the joint with an axial load will change the bolt extension and the joint compression (figure 4). Because the stiffness of the joint is typically five times or more the stiffness of the bolt, the effect of the axial loading is to primarily reduce the compression in the joint rather than extending the bolt. This point can be difficult to appreciate, but this is key to understanding why bolts are tightened rather than left loose.

Figure 5 shows a bolt and nut securing a bracket to a support plate. With the nut loose on the bolt, if a weight of 1 is added to the bracket, as shown in figure 6, then the force in the bolt shank will increase by 1. However, if the nut is now tightened and the weight applied, the force in the bolt shank will not increase by 1 but usually by only a small fraction of this amount. An understanding of why the bolt does not sustain the full effect of the applied load is fundamental to the subject.

A model can often be of help in understanding why the bolt does not sustain the full effect of the applied load. Figure 7 is an attempt to illustrate the load transfer mechanism involved in a bolted joint by the use of a special fastener. In the case of this fastener no significant load increase would be sustained by the fastener until the applied load exceeded the fastener’s preload (preload is the term used for a bolt’s clamp force).

With the special fastener shown, the bolt is free to move within its casing, a compression spring is included within the casing so that if the bolt is pulled down the spring will compress. A scale on the side of the casing indicates the force present in the spring and hence the force present in the shank of the bolt. Figure 7 illustrates this special fastener in its untightened condition.

The bolt is now inserted through a hole in a support plate and a bracket attached to the special fastener by securing a nut to the threaded shank. If the nut is now rotated...
will rapidly lead to fatigue failure of the bolt. This is because, if the thread is not sufficiently tight, the applied load will be distributed unevenly, leading to stress concentrations that can cause failure over time.

The bolted joint is a critical component in many mechanical systems, and it is essential to ensure that it is properly designed and loaded to avoid failures. The key factors to consider include the type of joint, the applied load, and the design procedures used to calculate the clamping force. By carefully considering these factors, engineers can design fastened joints that are safe and reliable.