



Guide to bolted joints and screw threads data

ESDU Copyright material. For current status contact ESDU.

Institution of
**MECHANICAL
ENGINEERS**

Endorsed by
The Institution of Mechanical Engineers

AVA Documents
Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Stress Analysis and Strength of Components Committee. This Committee first met in 1964 and now has the following membership:

Chairman

Prof. T.G.F. Gray — University of Strathclyde, Glasgow

Members

Mr J. Baghurst	— Independent
Dr B. Bhakta	— Meggitt Polymers and Composites, Loughborough
Dr I.J. Bickley	— Independent
Dr M. Heller*	— Air Vehicles Division, DSTO, Victoria, Australia
Dr J.W.H. Price*	— Integrity Partners, Australia.

* Corresponding Member

The ESDU Stress and Strength Series is recognised as a valuable source of validated data and methods by the Institution of Mechanical Engineers and its Structural Technology and Materials Group is involved in continually reassessing the scope and focus of the content of this Series.

The construction and subsequent development of the Data Item were undertaken by

Dr D.L. Downs — Senior Engineer

The person with overall responsibility for the work in this subject area is Mr A.C. Quilter, Head of Strength Analysis Group and Technical Director – Aerospace.

GUIDE TO BOLTED JOINTS AND SCREW THREADS DATA

CONTENTS

	Page
1. INTRODUCTION	1
2. GENERAL	1
2.1 Bolting Function	1
2.2 Pretension	1
2.3 Bolt Self-loosening	2
2.4 Thread Locking	3
2.5 Static and Fatigue Strength of Screwed Fasteners	4
3. DERIVATION	7
4. APPENDIX	9

GUIDE TO BOLTED JOINTS AND SCREW THREADS DATA

1. INTRODUCTION

Bolts and other threaded fasteners fulfil many different functions in engineering. The behaviour of bolted joints during assembly or in service can be quite complex and careful design of bolting systems is necessary to ensure proper performance. Bolted joints are used commonly to clamp components together or to react or transmit forces. They are also used to locate components in a particular position while allowing free sliding movement. In all cases it is important that connections do not loosen during the service life of the bolted artefact. The purpose of this note is to introduce the relationships between the various Data Items relevant to the design of bolted joints in the Stress and Strength of Components Series.

Note that other Data Items in the bolted joints and screw thread data Series, such as ESDU 66011^{*}, ESDU 71011[†] and ESDU 82022[‡] are not discussed here.

2. GENERAL

2.1 Bolting Function

For bolted joints, design strategies are based, in the first instance, on the nature and magnitude of loads applied within the system. Such loads may be axial and/or transverse with respect to the threaded fastener, and static or vibratory in nature. Any temperature variations that take place can result in differential strains which need to be accommodated, as do any vibratory loads with the potential to cause bolt self-loosening that may lead to fatigue failure. The phenomenon of bolt self-loosening is explained in ESDU TM 175 and the fatigue behaviour of bolted joints is covered in ESDU 67020, ESDU 67034, ESDU 80028, ESDU 84037, ESDU 96014 and ESDU 13008. Several other Data Items also contain information on the design of bolted joints and ways to minimise the fluctuating loads that cause fatigue failures in threaded components.

2.2 Pretension

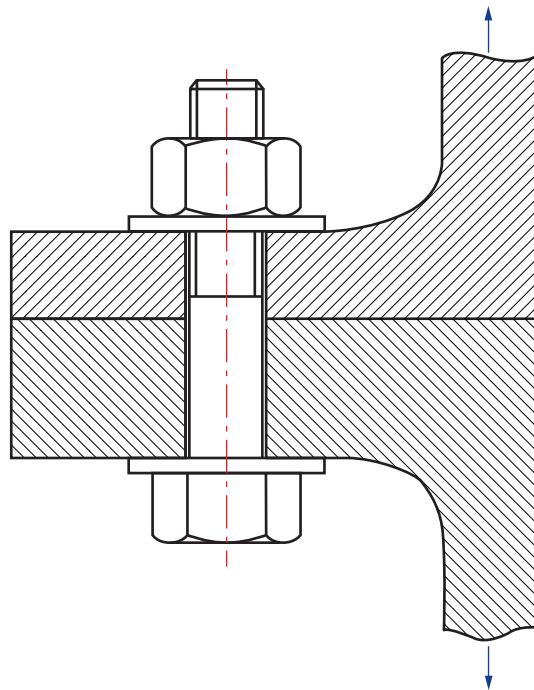
The integrity of a bolted joint always depends on the accurate application and retention in service of the axial tension in the threaded elements of the assembly. This is often called 'pretension' or sometimes 'initial tension' or 'pre-load' and is discussed in ESDU 14001. In general, bolt tension has three main effects. Firstly, as the pretension is linked directly to the rotational friction in the screw threads and at the nut or bolt head thrust faces, it will hinder any bolt unscrewing. Secondly, when a bolt is used to clamp together members that are subject to shear loads transverse to the bolt axis, the pretension increases the friction between the shearing faces thereby improving the shear load-carrying capability of the joint and reducing any tendency for self-loosening. Thirdly, when pretension is enough to maintain the contact force between the clamped members even if an external axial separating load is applied, this lessens any changes in the bolt axial load relative to the external load and reduces the likelihood of fatigue failure in the bolt.

The capability of a bolted joint to maintain pretension during service depends on the pattern of applied service load as well as other aspects of its design. ESDU 85021 deals with applying the pretensioning load and its effect on bolt forces for cases where the external load in service is in a direction that tends to separate the joint, thus increasing the axial forces. Such an analysis of loads requires information on the elastic stiffnesses of the clamped members and the threaded elements, see ESDU 13015 and ESDU 13016 for further information.

^{*} ESDU 66011, 'Loaded pins in axially loaded bars. Maximum elastic stress at hole boundary.'

[†] ESDU 71011, 'Stresses due to interference-fit pins and bushes in plates, strips or lugs.'

[‡] ESDU 82022, 'Endurance of steel lugs with clearance-fit pins (Tensile mean stress).'



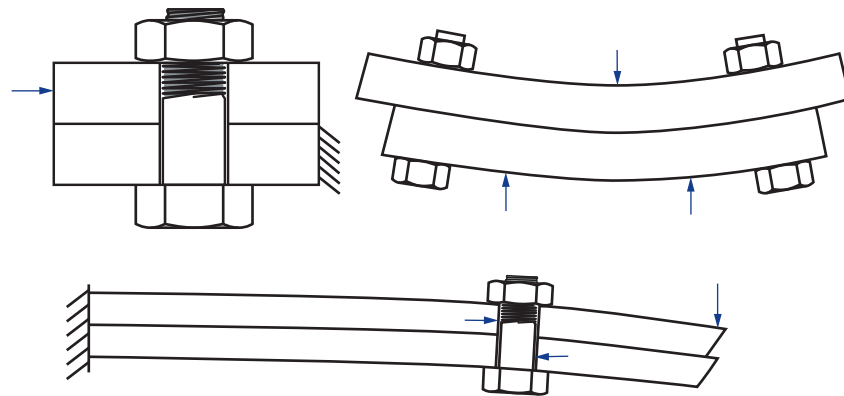
Simple bolted joint with an external applied load (ESDU 85021)

A correctly designed and pretensioned joint should remain closed, *i.e.* clamped, to some extent throughout its design life. As noted earlier, a properly clamped joint should reduce any fluctuations in the bolt load during cyclic loading and will improve the resistance of the joint to fatigue failures and bolt self-loosening. However, if the joint was to open or separate during external loading, any changes to the bolt load may increase the possibility of fatigue failure or bolt self-loosening.

The primary resistance to loosening of the threads is through the frictional resistance to any relative rotation of the engaging elements (the bolt, nut and the clamped members). The amount of frictional resistance depends directly on the axial forces in the system which gives further reason to ensure that the pretension is maintained under service loading conditions. However, there is usually some degree of axial relaxation after the pretension has been applied due to creep, settlement or similar in the joint. This leads to a drop in the pre-load, the amount of which depends on the reserve of elastic displacement in the pre-stressed elements in the joint. For this reason, it is preferable to design a bolted joint that has a large clamped thickness and that uses long, small-diameter bolts to provide as much elastic reserve against load reduction as possible (see ESDU 85021). This point is particularly important for machinery which experience cyclic temperature variations and component temperature differentials.

2.3 Bolt Self-loosening

In certain circumstances, bolts can self-loosen in service because of the relative motion of the threaded parts in the joint during repeated loading. Though the volume of research on this subject has increased significantly since around 1990, some aspects of this phenomenon remain unclear. Bolt self-loosening is more likely to happen if there are vibratory displacements of the clamped parts in the shear direction, normal to the bolt axis. Such displacements occur if the shear friction between the clamped member faces is not sufficient to prevent relative movement and this tends to happen if the design requirements to maintain pretension are not met, see ESDU 85021, ESDU 14001 and ESDU 13016 and ESDU TM 175. In general, bolt self-loosening is probable if the clamped length of the bolt is too short or there is not enough elastic reserve in the bolts or the clamped members to maintain the pretension in the event of non-elastic axial movement in the joint (*e.g.* through creep or extrusion of interface material).



Common causes of shear loading in bolted joints (ESDU TM 175)

Self-loosening occurs fundamentally because of the minute relative movements that take place in the shear direction between the bolt and/or the nut head face, and the clamped components. When this happens, the thread friction forces which normally resist unscrewing in statically loaded joints are overcome. The self-loosening rotation is driven by a loosening torque generated by tension in the bolt. Coarse pitch threads develop greater loosening torques than fine pitch threads.

If the conditions required for clamping and maintaining pretension in bolts are not met in the design, it is difficult to ensure that bolt self-loosening does not happen and recourse must be made to some kind of locking nut or similar to prevent relative rotation and unscrewing. ESDU TM 175 provides information and guidance on self-loosening of bolts.

2.4 Thread Locking

In situations when the self-loosening of bolts could happen, lock nuts or other thread locking devices are needed. They can also be used in cases where contact must be maintained between components sandwiched between a bolt and nut whilst avoiding the development of interface pressure. Such lock nuts and thread locking devices are described in ESDU 14002.

Lock nuts rely on some means of providing extra rotational friction compared to a plain nut. The extra friction is called 'prevailing torque', this being the torque required to rotate the nut freely when the bolt is not under tension. ESDU TM 175 discusses the relationship between self-loosening of bolts and the prevailing torque requirement in situations when such lock nuts are used. In the case of double plain lock nuts, the nuts are tightened against each other. This increases the rotational friction of the combined nut assembly on the bolt thread and consequently develops greater prevailing torques. Note that the assembly procedures for double plain lock nuts must be carefully controlled to achieve the required locking effect.

Locking can also be achieved using adhesives, by mechanical means (*e.g.* split pin), using special high-friction thread forms or by wedging bolt heads. Some experimental data on the resistance to loosening of these different systems is given in ESDU 14002.