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Fatigue strength of low-carbon steel stud threads under axial and combined axial and bending loading

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FATIGUE STRENGTH OF LOW-CARBON STEEL STUD THREADS UNDER AXIAL AND COMBINED AXIAL AND BENDING LOADING

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FATIGUE STRENGTH OF LOW-CARBON STEEL STUD THREADS UNDER AXIAL AND COMBINED AXIAL AND BENDING LOADING

1. INTRODUCTION

This Item examines the constant amplitude fatigue endurance behaviour of five types of studs that have been initially torque-tightened into blocks. The benefits of each type of stud are considered and their fatigue strength compared to that of bolts (ESDU 84037^{*}). An analysis of loading in assemblies has shown that the load paths, and consequently the fatigue strength of the studs, vary greatly with design.

A bolt is the general term to describe a threaded fastener used in conjunction with a nut to clamp two or more parts together. The term stud describes a rod with threads at both ends. When one end of the stud is torque-loaded into a block, this means that this threaded end of the stud is pre-tensioned (pre-loaded). If a top member is then positioned over the stud and fastened down using a washer and a nut, some of the pre-tension remains in the stud (assuming that the nut is assembled and tightened properly) regardless of whether or not an external load is applied to the top member. The fatigue behaviour of a stud is different to that of a bolt because pre-tension does not apply to bolts. Note that this pre-tension should not be confused with the pre-loading of studs and bolts that happens during clamping of the assembly.

In Section 3, fatigue endurance curves for low-carbon steel studs (and bolts) that have been axially loaded or loaded with a combination of axial loading and bending moment, are discussed. Sketch 3.1 shows the five types of steel stud and block designs and Sketch 3.2 presents the layouts used in the fatigue tests, see Figures 1 and 2. Note that the fatigue tests were carried out on the stud ends of the test-pieces only. The test studs shown on the left-hand side of Sketch 3.2 may be termed 'stud-bolts'. Stud-bolts are used as a convenient way to represent pre-tensioned studs in a fatigue test although in practice, stud-bolts cannot be pre-tensioned before being tensioned against a flange. Therefore, the fatigue strength of a stud-bolt is similar to that of a bolt and nut combination. 95/90 per cent confidence curves are calculated for the stud fatigue data and the upper and lower bounds of this group of confidence curves are shown on Figures 1 and 2.

The relative merits and the fatigue performance of the five test studs are discussed in Section 4.

In Section 5, the stud assembly behaviour is examined in terms of four stages of loading; screwing the stud into the block (Stage 0), assembling the flange/cover and tightening (Stage 1), applying the external load (Stage 2) and possible separation of the flange and the block when the external load is removed (Stage 3).

The implications of fatigue loading on steel studs are discussed in Section 6 along with the effects of superimposed bending and other factors that may influence the fatigue properties.

In Section 8, two worked examples to calculate the fatigue strength of stud threads screwed into the block are given. These examples present stiffness calculations in the stud assembly and the associated loading diagrams.

^{*} ESDU 84037, 'Fatigue strength of external and internal steel screw threads under axial loading (standard forms not greater than 1.0 inch diameter)'.

2. NOTATION

Both SI and British units are quoted but any coherent system of units may be used.

A	area	m^2	in^2
A_t	tensile stress area of stud threads	m^2	in^2
$\odot$	contact point position		
d	stud shank diameter	m	in
E	Young's modulus	N/m^2	lbf/in^2
f_t	tensile strength	N/m^2	lbf/in^2
f_y	yield strength	N/m^2	lbf/in^2
k	stiffness	N/m	lbf/in
l	length	m	in
$M(x)$	bending moment	N m	lbf in
N	endurance	cycles	cycles
P	load	N	lbf
P_a	alternating axial load in stud shank	N	lbf
p_0	pre-tension	N	lbf
R	radius	m	in
S_a	alternating axial stress (stress amplitude) = P_a/A	N/m^2	lbf/in^2
T	torque	N m^2	lbf in^2
x	distance	m	in

2.1 Suffixes

<i>acl</i>	applied clamping load	<i>nut</i>	nut
<i>app</i>	applied external load	<i>s</i>	stud shank
<i>b</i>	stud-block interface (butt)	<i>sep</i>	separation of flange from block
<i>collar</i>	collar	<i>stud</i>	total for all parts of the stud assembly
<i>f</i>	flange	0	Stage 0 – screwing the stud into the block
<i>flange</i>	total for all parts of the flange assembly	1	Stage 1 – assembly of the flange and tightening
<i>max</i>	maximum	2	Stage 2 – applying the external load
<i>min</i>	minimum	3	Stage 3 – separation of the flange from the block
<i>n</i>	stud neck		

2.2 Sign Convention

Tensile loads in the studs are positive. Compressive loads in the flange and block are positive.

3. NOTES

3.1 General

Figures 1 and 2 present room temperature fatigue endurance data for 25.4 mm (1 in) diameter low-carbon steel studs that have been loaded axially or loaded with a combination of axial load and constant bending moment, respectively. Details of the five test studs and the layout of the tests are given in Sketch 3.1, 3.2 and 3.3, and Table 9.1. The fatigue tests were carried out on the stud ends of the test-pieces only. The fatigue endurance curves in Figures 1 and 2 have been plotted using ESDU 97024*. During the tests, the minimum load remained constant as the maximum load varied.

The fatigue endurance curves in Figures 1 and 2 are from studs with machined and chased Whitworth threads. The stud threads were not lubricated. This Item is relevant to any stud with standard machined threads (metric, UNF, BA *et cetera*) because the fatigue strength of studs is determined by the method of thread manufacture so the thread form is not important (see ESDU 84037).

In Figures 1 and 2, the fatigue endurance data are presented in terms of the load in the stud shank. This load is different to the applied external load, which usually acts only on the flange, and the load in the stud neck. Loads in the stud shank can be calculated using the methods in Section 4 and Section 8.

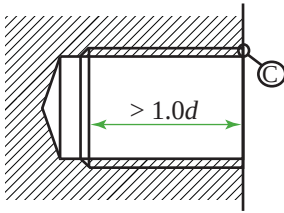
The data in Figures 1 and 2 are available in the MicrosoftTM Excel file, E13008v10.xlsx, which accompanies this Item. (Note that the values given in the file are not the actual test results but are values digitised from figures in the Derivations.) 95/90 per cent confidence curves have been found for the fatigue data from the five test studs and the upper and lower bounds of this group of confidence curves are shown on Figures 1 and 2. On Figure 1, the fatigue data for machine cut bolt threads from ESDU 84037 are not included in the band of confidence curves.

The fatigue data in this Item are the results of laboratory tests carried out under specific conditions that may not reflect what is observed in practice. ESDU 84037 suggests that pre-tensioning applied to the studs and chasing of the stud threads could be responsible for lower endurance levels when compared to machine cut bolts.

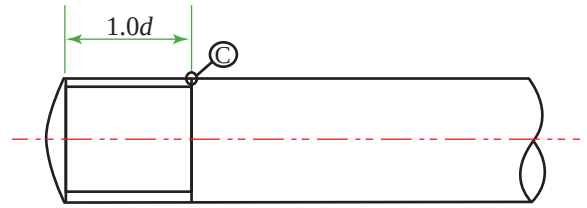
From Figures 1 and 2, for a given tightening torque, the relieving groove stud gives the best fatigue performance. This is followed, in turn, by the recessed-block stud, the collared stud and then the normal stud design. The bottoming stud offers the lowest fatigue strength.

* ESDU 97024, 'Derivation of endurance curves from fatigue test data, including run-outs'.

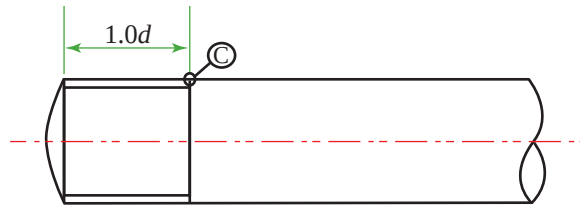
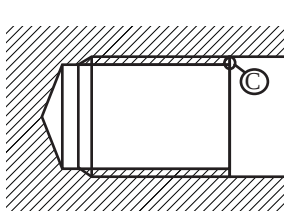
Block



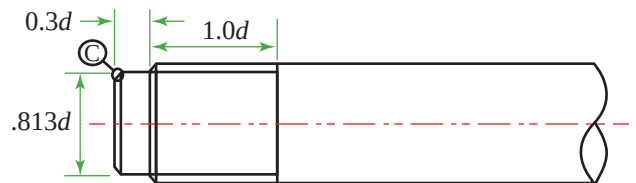
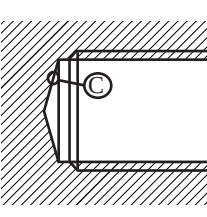
Stud



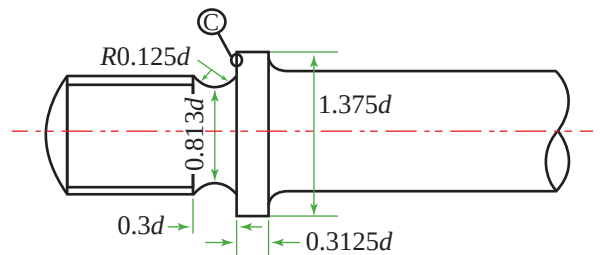
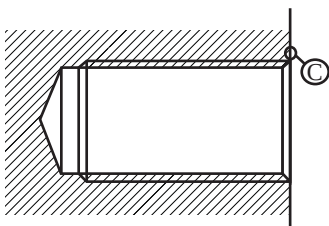
a. Normal stud



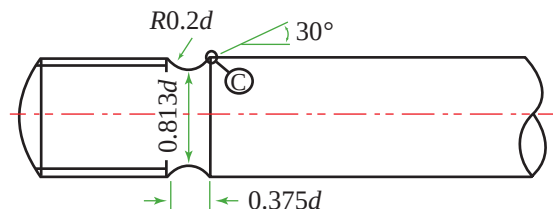
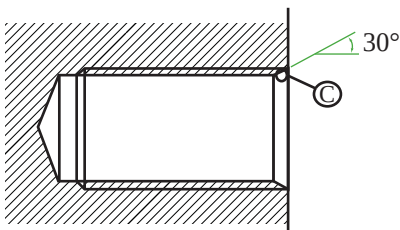
b. Recessed-block stud



c. Bottoming stud



d. Collar stud



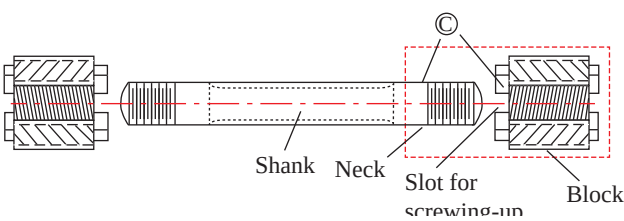
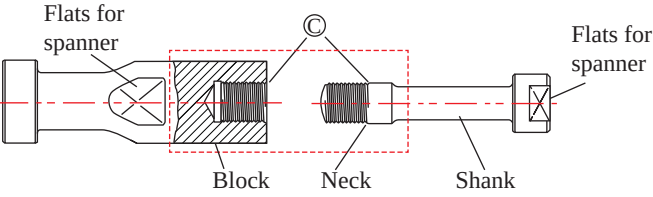
e. Relieving groove stud

© indicates the contact point (shown in one position only) between the stud and the block

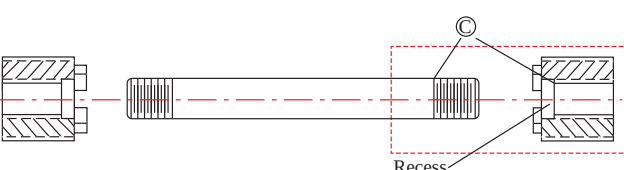
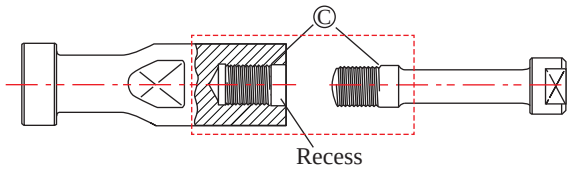
Sketch 3.1 Stud and block designs for which data are presented

For Figure 1:

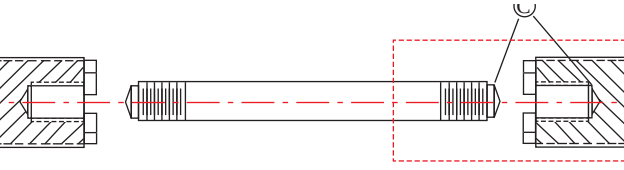
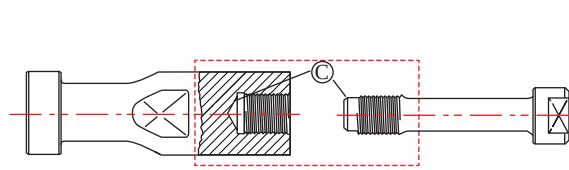
For Figure 2:



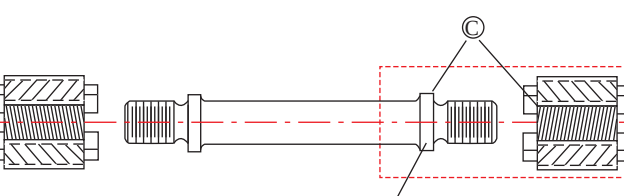
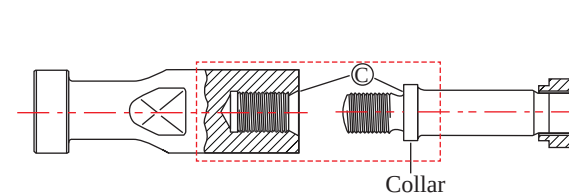
a. Normal stud



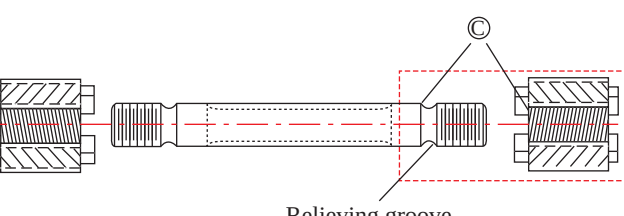
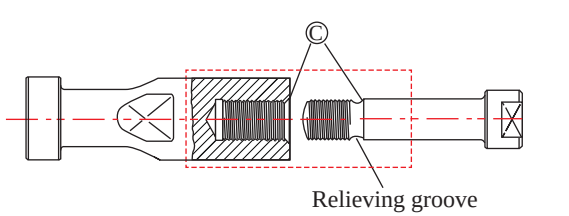
b. Recessed-block stud



c. Bottoming stud

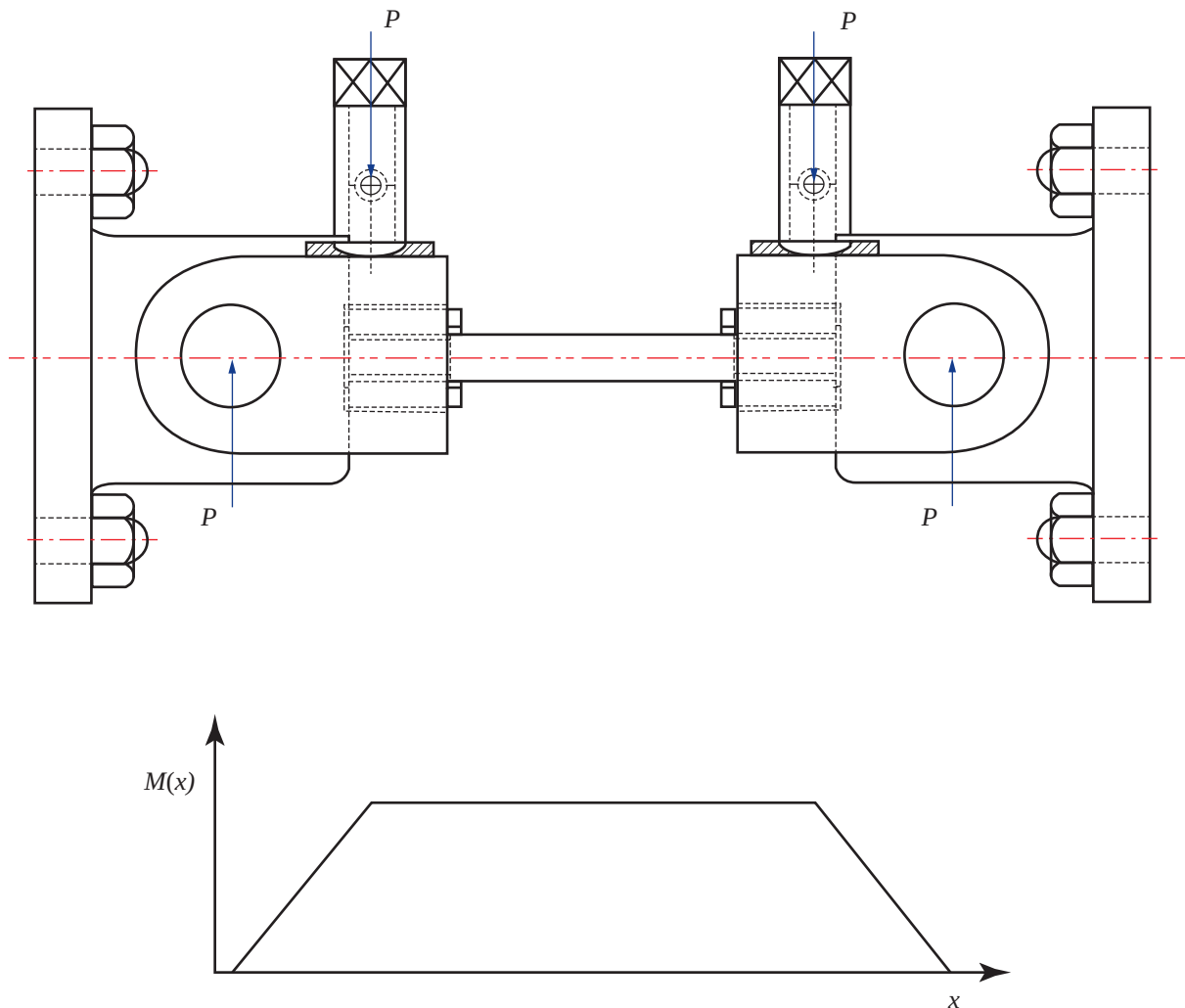


d. Collar stud



e. Relieving groove stud

Sketch 3.2 Layouts of studs and blocks for Figures 1 and 2



Sketch 3.3 Bending fixture arrangements for studs in Figure 2

3.2 Axial Loading Tests

Figure 1 presents fatigue data for the five types of studs during direct axial loading fatigue tests (Derivation 1). The test studs in Figure 1 was manufactured from low-carbon steel. The studs were inserted into a socket and, following a brief survey of the average tightening torque normally applied to fitting 25.4 mm (1 in) studs, the studs were tightened to a torque of 217 N m (1920 lbf in). The pulsating tension tests were carried out under pure axial loading with a minimum stress of 46.3 MN/m² (6720 lbf/in²) applied directly to the head in every case.

All of the studs in Figure 1 failed by simple fracture with cracks beginning at the first engaged thread in each instance.

No information was available regarding the possible relaxation of the pre-tension or the lifting-off of the stud from the block.

Also shown on Figure 1 is a fatigue curve for bolts with machine-cut threads taken from ESDU 84037. Stress in the bolts and the studs is found by dividing the load in the shank by the core thread area. For bolts, the load in the shank is equal to that in the neck. However for stud, the load in the shank is not the same as that in the neck and the load in the true stud neck load cannot usually be calculated because it depends on the amount of pre-tension (Derivation 1).

3.3 Combined Axial Load and Bending Moment Tests

Figure 2 presents fatigue data for the five types of studs subjected to combined axial loading and bending moment fatigue tests (Derivation 2). All of the studs in Figure 2 were manufactured from low-carbon steel and the studs were threaded at both ends. A screwing-up torque of 217 N m (1920 lbf in) was applied in each case. A uniform bending moment was applied to the studs by means of a four-point loading fixture in which two screws were tightened equally until a central deflection was set up, corresponding to a bending moment of 88.6 N m (784 lbf in), Sketch 3.3. For each test, the maximum axial load was varied and the minimum axial load remained at 19 930 N (4480 lbf). The minimum applied axial load represents a stress of 55.9 MN/m² (8100 lbf/in²) in the root area of the stud, the diameter of which is 21.3 mm (0.84 in).

No mention was made of the studs lifting-off from the block in any of the tests, and no information was given about the relaxation of the pre-tension. The stress-relieving effect on the stud pre-tension by the stresses induced by the bending moment was not clear therefore no reduction was assumed. When a static bending moment is combined with a fluctuating direct axial load, there will be a significant reduction in fatigue life because of larger stresses.

In Figure 2, all of the studs failed by simple fracture with cracks beginning at the first engaged thread for each stud. No direct comparison can be made between the fatigue endurance behaviour of the studs in Figure 1 and Figure 2 because the studs in the combined axial loading and bending moment tests had a lower tensile strength and a slightly higher minimum stress compared to the studs in the axial loading only tests. In Figure 2, the induced bending stress varies with each type of stud as the stud-seating absorbs different proportions of the bending displacement. The relative strength of each type of stud is the same for Figure 1 and Figure 2 (*i.e.* the relieving groove studs were the best and the bottoming studs were the worst, *et cetera*).

4. STUD AND BLOCK DESIGNS

The relative merits of the five types of stud design shown in Sketches 3.1 and 3.2 are discussed below. Sketch 3.1 and 3.2 show the region of “bottoming” contact – position © – between the stud and the block (the position where the force induced by the applied tightening torque is mainly reacted).

4.1 Normal Studs

The normal stud has no positive seating when initially screwed in and torque-tightened. The applied torque is reacted directly at the thread run-out (the neck) and, since this lies at one side of the stud, bending of the stud thread is induced. The first thread experiences the full stud-alternating load and, with added bending stress, there is a danger of failure in the block at this thread.