

Guide to design considerations on

The strength of screw threads

Confirmed
January 2012

Co-operating organizations

The Mechanical Engineering Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Admiralty*	Gas Council
Air Ministry	High Commission of India
Associated Offices' Technical Committee	Institute of Marine Engineers
Association of Consulting Engineers (Incorporated)	Institute of Petroleum
Association of Mining Electrical and Mechanical Engineers	Institution of Civil Engineers*
British Chemical Plant Manufacturers' Association	Institution of Gas Engineers
British Compressed Air Society	Institution of Heating and Ventilating Engineers
British Electrical and Allied Manufacturers' Association*	Institution of Mechanical Engineers*
British Gear Manufacturers' Association	Institution of Mechanical Engineers (Automobile Division)
British Internal Combustion Engine Manufacturers' Association	Institution of Production Engineers*
British Iron and Steel Federation	Locomotive and Allied Manufacturers' Association of Great Britain*
British Mechanical Engineering Federation*	London Transport Board*
British Railways Board*	Machine Tool Trades Association
Crown Agents for Oversea Governments and Administrations	Ministry of Labour (H.M. Factory Inspectorate)
D.S.I.R. National Engineering Laboratory*	Ministry of Power
Electricity Council, the Generating Board and the Area Boards in England and Wales	Ministry of Public Buildings and Works
Engineering Equipment Users' Association*	Ministry of Transport
	National Coal Board
	National Physical Laboratory (D.S.I.R.)*
	Radio Industry Council*
	War Office*

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following were directly represented on the Committee entrusted with the preparation of this standard:

Agricultural Engineers' Association	Scientific Instrument Manufacturers Association
British Bolt, Nut, Screw & Rivet Federation	Screw Thread Tool Manufacturers Association
British Ship Research Association	Society of British Aircraft Constructors
Electronic Engineering Association	Society of Motor Manufacturers & Traders Ltd.
Ministry of Aviation	Telecommunication Engineering & Manufacturing Association
National Association of Marine Engine Builders	

This Guide, having been approved by the Mechanical Engineering Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 28 February 1964

© BSI 12-1999

The following BSI references relate to the work on this standard:
Committee references MEE/1, MEE/1/2
Draft for comment A(MEE) 9770

ISBN 0 580 35254 4

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
Co-operating organizations	Inside front cover
Foreword	ii
Introduction	
1.1 Scope	1
1.2 Symbols	1
General	
2.1 Introduction	1
2.2 Design principles	1
2.3 Form of bolt failure	2
2.4 Tensile strength of bolt related to stress area	2
2.5 Stripping strength	3
2.6 Fatigue strength	3
Materials	
3.1 Tensile strength	3
3.2 Fatigue strength	4
Method of production	
4.1 General	4
4.2 Cold rolling	4
4.3 Root-rolling	4
General form of threaded members and type of loading	
5.1 Introduction	4
5.2 Stripping strength	5
5.3 Thread load distribution and fatigue strength	5
5.4 Impact strength	8
Diameter, pitch, D/p ratio, and length of engagement	
6.1 Stripping strength	8
6.2 Tensile strength	9
6.3 Fatigue strength	9
Thread form	
7.1 Stripping strength	10
7.2 Fatigue strength	10
Depth of engagement, degree of fit and truncation of threads	
8.1 Stripping strength	11
8.2 Fatigue strength	11
Friction conditions	
9.1 Introduction	12
9.2 Effect of torsional stress	12
9.3 Clamping load	12
9.4 Fatigue strength	13
Appendix A Formulae for thread shear areas and length of engagement	14
Appendix B Torque-tension relations	15
Appendix C Symbols	17
Appendix D References	18
Figure 1 — Forms of nut giving improved thread load distribution	6
Figure 2 — Theoretical load distribution along thread helix	7

Foreword

This guide makes reference to the following British Standards:

BS 1083, *Precision hexagon bolts, screws and nuts*.

BS 1580, *Unified screw threads — Parts 1 and 2: Diameters $\frac{1}{4}$ in and larger*.

BS 1768, *Unified precision hexagon bolts, screws and nuts (UNC and UNF threads) — normal series*.

BS 3139, *High strength friction grip bolts for structural engineering — Part 1: General grade bolts*.

BS 3294, *The use of high strength friction grip bolts in structural steelwork — Part 1: General grade bolts*.

This guide has been prepared under the authority of the Mechanical Engineering Industry Standards Committee to serve as a guide to the design of load-bearing screwed connections. Its aim is to make designers aware of the various factors influencing the strength of such connections and to give some estimate of the effect of these factors.

As the present degree of knowledge in the field is insufficient to warrant the inclusion of precise formulae of general applicability, no attempt has been made to present detailed calculations. Where values or formulae have been given, it should be appreciated that these represent the best approximations which can be given in the light of available knowledge. It is hoped that they will be refined and extended in future revisions of this guide as a result of further investigation.

Permission to reproduce from the N.B.S. Handbook H 28 (1957) Part 1, text relating to thread shear areas and lengths of engagement, has been kindly granted by the National Bureau of Standards of America. This text is included herein as Appendix A, to be used as an interim measure, to calculate the static stripping strength.

Appendix B concerns torque-tension relations and the effect of thread friction on permissible tightening stresses.

NOTE In place of the customary, but incorrect, use of the ton as a unit of force, the unit called ton-force (abbreviation tonf) has been used in this guide.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 19 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

1.1 Scope

This guide relates to applications of triangular (V-form) screw threads where strength considerations have to be borne in mind. It is intended to draw the attention of designers to the principal strength factors to be considered in following out details of a design, with some mention of measures which may be adopted to improve strengths. The guide has been largely based on results obtained with steel components and while many of the considerations will apply to other materials, care should be exercised in the interpretation of certain data. For quantitative data, it will often be necessary to refer to an appropriate source of information, such as a component or material manufacturer or a Government laboratory, though it is emphasized that information on many aspects of the subject is still inadequate.

The guide also relates to behaviour at temperatures where creep and metallurgical changes are unimportant and is concerned with screwed connections, i.e., with “bolt” and “nut” combinations; the strength of a threaded bar, not assembled with a nut, is not considered. For the latter, reference should be made to appropriate theoretical and experimental work on notched and threaded bars ⁽¹⁾ ⁽²⁾¹⁾.

NOTE “Nut” and “bolt” are used throughout in the general sense to mean internally and externally threaded members respectively, except where it is obvious that ordinary nuts and bolts are meant.

The effect of the various strength factors are considered under the following headings:

Materials

Method of production

General form of threaded members and type of loading

Diameter, pitch, D/p ratio and length of engagement

Thread form

Depth of engagement, degree of fit and truncation of threads

Friction conditions.

1.2 Symbols

For ease of reference, symbols used throughout this guide are listed in Appendix C.

General

2.1 Introduction

To a given problem of thread design, there may be several solutions, between which it is not possible to choose in the light of present knowledge. The preliminary choice of the general lines of a design must therefore still be based, to some extent, on previous experience with similar problems.

2.2 Design principles

A threaded fastener will usually have to be designed to withstand axial loads, which may be static, fluctuating, or impactive in nature. Supplementary bending and shear may be present; torsional loads will arise mainly from thread friction on tightening and will be static in nature. The strength of a *joint assembly* employing threaded fasteners will largely depend, particularly under fluctuating loads or shear loading such as occur in structural steelwork²⁾, on the overall design and provision of adequate pre-tensioning; the latter will, of course, demand adequate static strength of the fasteners employed. Bearing this in mind, the following is a discussion of the factors affecting the *intrinsic* strength of threaded connections, with only brief reference to the effects of joint design.

¹⁾ A list of references is given at the end of this guide.

²⁾ See BS 3139, “*High strength friction grip bolts for structural engineering*”. and BS 3294, “*The use of high strength friction grip bolts in structural steelwork*”.

It will be appreciated that the factors considered are often interrelated, e.g., the optimum tensile strength of the nut material for a given bolt may depend not only on the tensile strength of the bolt material but also on the pitch and diametral fit of the threads. At the same time, while it may be desirable to try to achieve the optimum combination of materials and dimensions for a special application, it is necessary for ordinary mass-produced bolts and nuts to use a restricted number of material combinations, each of which will have to serve for a range of other variables, e.g. for various classes of fit. Thus, for instance, it may be economically preferable to accept the strength of stock components, and to design accordingly rather than to design for the higher strength available from the use of special components.

2.3 Form of bolt failure

It is desirable, where possible, to design a fastener so that failure under tensile load would occur by breakage across the core of the bolt, rather than by thread stripping. The latter form of failure, which begins by thread bending and ends by shearing of the internal and/or external threads, tends to be gradual in nature, and progressive in cases of repeated assembly. Such damage is not always easy to detect, particularly if the main damage is to internal threads; this introduces the possibility that serious overtightening on assembly may remain undetected until evidenced by failure in service. Again, if failure occurs by stripping, this indicates uneconomic use of the material of the bolt, the full core strength of which is not developed.

2.4 Tensile strength of bolt related to stress area

Tensile strength of bolt. Where failure occurs across the core of the bolt, the tensile strength should be computed as the product of the ultimate tensile stress of the material and the tensile stress area A_s : where

$$A_s = \frac{\pi}{4} (\text{Mean of effective and minor diameters})^2$$

$$= \frac{\pi}{16} (\text{Effective diameter} + \text{minor diameter})^2.$$

The use of the stress area A_s has been found to give a reasonable approximation to the condition which prevails at the point of fracture.

Tensile stress areas for Unified threads. The tensile stress areas for Unified threads, which are quoted in BS 1580-1³⁾ are calculated by the above formula⁴⁾ using basic effective and design minor diameter. For ¼ in diameter threads, Class 1A, in the minimum metal condition, the stress area is less than the quoted values by only about 8 per cent for UNC and 6.5 per cent for UNF and UNEF. This difference decreases with increasing diameter and for 1½ in threads is only about 3 per cent for UNC and 1 per cent for UNF and UNEF. The corresponding differences for Class 2A threads are about 1 per cent less than those for Class 1A. If such differences are considered to be important in a particular application, design should be based on minimum metal dimensions for the class of thread employed.

³⁾ BS 1580, "Unified screw threads", Parts 1 and 2, "Diameters ¼ in and larger".

⁴⁾ For Unified external threads,

$H = 0.86603p$, then $E_s = (D - \frac{3}{4}H)$, $K_s = (D - \frac{17}{12}H)$ and the formula reduces

to $A_s = \frac{\pi}{4} (E_s - \frac{H}{3})^2 = \frac{\pi}{4} (E_s - 0.28867p)^2 = 0.7854(D - 0.9382p)^2$. This formula correlates with test results for steels up

to 45 tonf/in² tensile strength. For steels of greater tensile strength, the basic effective diameter should be replaced by the minimum effective diameter for the class of thread in question.

2.5 Stripping strength

The stripping strength of a threaded combination is not easy to compute: formulae based on “shear areas” are unrealistic, as they incorrectly assume that shear occurs in threads not previously deformed by bending, and that the internally threaded member suffers no radial expansion; the latter assumption is quite inaccurate for the lighter series nuts at failure loads; expansion will, of course, decrease with increasing wall thickness. Again, if the stripping load is high enough to cause prior yield of the body of the bolt, “necking” of the latter will reduce depth of engagement in a manner similar to that caused by nut expansion, and plastic elongation of the bolt (increase of pitch), will necessitate severe deformation of engaging nut threads, especially near the bearing face. Also, the stripping load of a given nut depends on the hardness of the bolt; as this is increased, bending of the bolt threads at the nut failure load will be reduced and shearing will take place nearer the root of the nut threads, which will increase the nut stripping load. The foregoing argument will, of course, apply to the stripping strength of a bolt fitting into a nut of harder material, a case which is sometimes unavoidable.

Despite the inadequacy of formulae based on the “shear area” of undistorted threads, this approach is at present the only one generally applicable to the calculation of stripping strength, although the onset of thread yield, which is due to bending, may be estimated from Sopwith’s analysis. ⁽³⁾ Until more experimental data can be acquired, therefore, it is suggested that use be made of Appendix A to this guide, which has been copied from pages 5 and 6 of the American “Screw-thread Standards for Federal Services”, Handbook H.28 (1957), Part I, with some slight modifications and the addition of formulae for Whitworth threads. Wherever possible, the values of critical length of engagement should be checked experimentally, especially for the higher D/p ratios, where such experimental evidence as is available indicates that the formulae give lengths of engagement which are too low.

2.6 Fatigue strength

Fatigue stresses quoted for screwed connections are usually nominal stresses computed on the core area of the bolt, i.e. $\frac{\pi}{4}(\text{minor diameter})^2$. Fatigue strength actually depends on the maximum true stress which is much higher than the nominal, and on the stress distribution, which is non-uniform. (See 5.3). These are difficult to estimate accurately and in any case bear no particular relation to the “stress area” for static loading. It must be borne in mind that a fatigue strength quoted as a nominal core stress will not necessarily apply to a threaded combination different from the one on which the determination was made, due to differences in the actual stress distributions.

Some information on the fatigue strength of steel bolts, $\frac{1}{4}$ in to $\frac{3}{4}$ in diameter, is contained in Ref. 21.

Materials

3.1 Tensile strength

Material. The nut material should, where possible, be somewhat softer than the bolt material. The ratio of the tensile strength of the nut material to that of the bolt material, necessary to develop the full tensile breaking load of the bolt, increases with diameter/pitch ratio. This is due to the lower stripping strength of fine threads, as described in 6.1. For threads as fine as UNF this tensile strength ratio should not generally be less than 0.85 when using a solid bolt, though a ratio of about 0.75 should suffice for threads near basic dimensions (see also 6.2).

Increased tensile strength. Increasing the tensile strength of the bolt material above about 60 tonf/in² does not usually result in much increase of fatigue strength in cases of severe stress concentration as obtained in threaded connections (this does not necessarily apply to bolts with threads cold-rolled after heat treatment where fatigue strength is largely dependent on the condition of the surface layer. See 4.2). Since tight clamping can, however, ensure that the load in the bolt is increased by only a fraction of the load applied externally to a joint assembly ⁵⁾, high tensile strength bolts are often advantageous, particularly in saving space and weight.

3.2 Fatigue strength

Increased fatigue strength. Use of a nut material with an elastic modulus lower than that of the bolt improves the elastic thread load distribution. Thus, increases in fatigue strength of up to 40 per cent have been reported for steel bolts assembled with cast iron or light alloy nuts, as compared with steel nuts. The length of engagement in a relatively weak nut material must, of course, be great enough to provide adequate static stripping strength.

Method of production

4.1 General

Effect of different machining methods. The various machining methods produce threads not varying greatly in strength, provided that finish, and accuracy of thread form and pitch are comparable, and that faults, such as grinding cracks or unfavourable residual stresses, are not introduced. The latter defects would have an adverse effect on fatigue strength, while having little or no effect on static strength.

4.2 Cold rolling

Cold rolling can produce bolt threads with greater strength than machined threads. The static strength is only increased by a few per cent but, in suitable materials, the fatigue strength can be greatly increased, e.g., by 50 to 100 per cent for bolt steels. ⁽⁹⁾, ⁽¹⁰⁾ and ⁽²⁾ Chap. 8. Where applicable, this method is probably the most effective one for increasing the intrinsic fatigue strength of a screwed connection. Some attention must be paid to rolling conditions in order to obtain optimum results and further research is desirable on the effect on fatigue strength of such factors as rolling time, rolling pressure and rate of penetration. (See also 7.2). The increased strength, as compared with cut threads, is due to residual compressive stress in the thread roots, together with work hardening and improvement of grain flow. Subsequent heat treatment will reduce the fatigue strength again in the measure of the severity of this treatment, e.g. complete re-hardening and tempering will reduce the fatigue strength to that of a thread cut after the same heat treatment, whereas a low temperature stress relief may only cause a moderate reduction from the optimum due to loss of some residual compressive stress, the favourable grain flow being retained. Excessive decarburization will reduce the static stripping and fatigue strengths for any method of production.

4.3 Root-rolling

Improvements similar to those for full-form rolling can be obtained from root-rolling of pre-cut threads. ⁽¹⁰⁾ This method is useful for special threads and large diameters.

General form of threaded members and type of loading

5.1 Introduction

Form of fasteners. Apart from the overall design of the joint, the general form of the threaded members themselves has some effect on their strength.

⁵⁾ For an external load P applied to the outer ends of the clamped members, the resultant load in the

bolt is $P_B = P_0 + P \left(\frac{C_B}{C_M + C_B} \right)$, where P_0 is the initial load in the bolt developed by tightening the nut and C_B , C_M are

respectively the stiffnesses of the bolt-nut combination and of the clamped members (loads per unit deflection along the bolt

axis). This applies for values of P where the load for joint separation, which is equal to $P_0 \left(\frac{C_M + C_B}{C_M} \right)$ and is proportional to P_0 , is

greater than P . Where the separating load is less than P , the whole of the external load is borne by the bolt.

For further discussion of this matter see refs. ⁽⁴⁾, ⁽⁵⁾, ⁽⁶⁾, ⁽⁷⁾, ⁽⁸⁾.