SCI PUBLICATION P324

Tension Control Bolts, Grade S10T, in Friction Grip Connections

T C Cosgrove BSc MSc CEng DIC MIEI MIStructE

Published by:
The Steel Construction Institute
Silwood Park
Ascot
SL5 7QN

Tel: 01344 623345
Fax: 01344 622944

With sponsorship from:
Tension Control Bolts Ltd
Whitchurch Business Park
Shakespeare Way
Whitchchurch, SY13 1LJ

Tel: 01948 667700
Fax: 01984 667744

Publication Number: SCI P324

ISBN 1 85942 156 3

British Library Cataloguing-in-Publication Data.

A catalogue record for this book is available from the British Library.

FOREWORD

The particular form of tension control bolt covered by this publication has been developed in Japan from a concept first introduced in the UK many years ago; Torshear bolts. This bolt, known as a Tension Control Bolt, Grade S10T, is readily available in the UK. However, the manufacture of the bolt and its method of tightening are not explicitly covered by British or European Standards. This design guide has been prepared to assist designers and specifiers in using this type of bolt for structures in the UK.

The author of this guide is Thomas Cosgrove of The Steel Construction Institute. Technical assistance and comments during drafting were provided by Charles King, David Brown and Andrew Way, all of The Steel Construction Institute.

Ivor Ryan of CTICM, France, has carried out a technical review of this design guide and his advice, input and comment are very gratefully acknowledged.

This guide has been prepared with sponsorship from Tension Control Bolts Ltd. of Whitchurch, Shropshire England. They also provided detailed information about the dimensions and properties of TCBs Grade S10T.

Contents

SUMMARY

This publication provides an 'industry standard' for the design of structural steelwork connections using preloaded Tension Control Bolts Grade, S10T (TCBs). These fasteners and tightening technology are of Japanese origin and this publication provides advice in the interpretation of the preloaded bolt standards in the UK in regard to TCBs. A design method for preloaded TCBs Grade S10T that satisfies the recommendations of BS 5950-1:2000 and BS 5400-3:2000 is given.

A description of the tightening process, an outline of the manufacturing specifications and procurement requirements are also included. Worked examples are provided, illustrating the design of typical steelwork connections using preloaded TCBs Grade S10T.

Design tables are given for connections using TCBs; the tables give bearing, shear, slip and tensile resistances according to BS 5950-1 and BS 5400-3.

1 INTRODUCTION

Tension control bolts (TCBs), are a type of high-grade bolt that can be preloaded by a tightening process that is carried out entirely at the threaded end (i.e. at the nut or spline end) of the bolt. Consequently, TCB's are usually distinguished by their round heads (rather than hexagonal heads) and splines.

One particular type of TCB, manufactured by Tension Control Bolts Limited, has been used in the U.K. and Europe for over ten years. This bolt, referred to, as "TCB Grade S10T" is a Grade 10.9 bolt. The bolt and the tightening technology are of Japanese origin, where they are extensively used.

In the UK, the use of TCBs as 'friction grip bolts' gives rise to difficulties in the interpretation of the applicable British Standards, BS 4395-2 and BS 4604-2. This is because neither of these standards caters for higher-grade (10.9) bolts that can sustain applied tension, or for tension control bolts, which are tightened in a different way from the methods covered by the Standards. Further, the draft European standard for preloaded bolts, issued for comment in 2001, does cater for applied tension on high-grade (10.9) preloaded bolts but does not yet have a section catering for tension control bolts. It is expected that this omission will be remedied in the next few years.

In the absence of a national standard, this design guide provides an 'industry standard' for the design of connections using preloaded TCB Grade S10T fasteners.

For buildings in the UK, BS 5950[1] refers specifically to BS 4395[2] and to BS 4604[3] for friction grip fasteners. However, BS 5950-1:2000, Clause 3.2.2 and BS 5950-2:2001, Section 2.2 permit the use of other types of friction grip fasteners, provided that they can be reliably tightened to at least the minimum shank tension specified in BS 4604. Both the *National Structural Steelwork Specification for Building Construction*[4], and BS 5400[5] (for bridges) have similar clauses.

A TCB Grade S10T can be preloaded to at least the minimum shank tensions specified in BS 4604-2 and hence may be used as a friction grip fastener. In fact, the minimum preload induced by the tightening procedure used on a TCB Grade S10T exceeds the minimum requirements of BS 4604-2. This design guide presents, in tabular format (Appendix C), slip resistance values for TCB Grade S10T fasteners, based on preload values that have been demonstrated by test to be reliably achieved by the tightening process for these bolts. The values of preload are consistent with those given in the more recent design standards, such as Eurocode 3.

WARNING: Since this design guide takes advantage of the extra preload induced in TCB Grade S10T fasteners, their resistance will be higher than that of the same diameter bolt to BS 4395-1 or BS 4395-2. Therefore, a 'Part 1' or 'Part 2' bolt to BS 4395 must not be directly substituted for a TCB Grade S10T, designed in accordance with this design guide. On the other hand, a TCB Grade S10T can be directly substituted for a bolt to BS 4395 in a connection that has been designed to BS 5950-1:2000 or BS 5400-3:2000.

Further, the preloads used in the design tables have been validated only for the particular TCB Grade S10T fasteners that are manufactured by Tension Control Bolts Ltd. **The design tables should not be used for any other type of tension control bolt or any similar fastener supplied by another manufacturer.**

2 TCB GRADE S10T FASTENERS

2.1 Description

TCB Grade S10T fasteners are high-strength (10.9), high-ductility (14%) friction grip bolts for use in structural steelwork connections. Their primary advantage (over other types of friction grip bolt) is the ease of preloading the bolts.

The fastener assembly is illustrated in Figure 2.1. Preloading is carried out by an electrical shear wrench at the threaded end of the bolt i.e. the nut or spline end. At the other end, the head of a TCB, Grade S10T is round compared to an hexagonal head for normal bolts, making a TCB, Grade S10T quite distinctive in appearance.

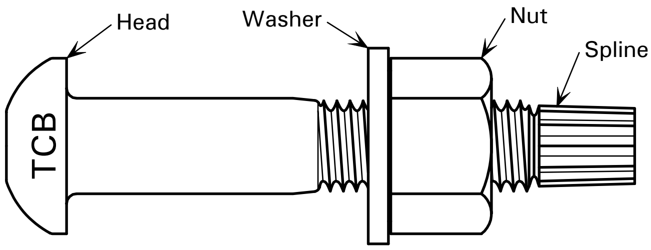


Figure 2.1 *TCB, Grade S10T (Prior to Preloading)*

TCB Grade S10T fasteners are sometimes used in bearing or slip connections where preloading is not required.

2.2 Design of steelwork connections using TCB Grade S10T

Steelwork connections using TCB Grade S10T may be designed to the provisions of BS 5950, BS 5400, Eurocode 3 and CM 66 (in France). A design basis for bolted connections using preloaded and non-preloaded TCB Grade S10T is set out in Section 3; the specified minimum preloads are given in Section 3.2.2.

Owing to the high ductility of the bolts (14%) no restrictions need be placed upon the use of the bolt in direct or applied tension, unlike the restrictions on the use of bolts to BS 4395-2 and BS 4604-2. Thus TCB Grade S10T can sustain co-existing shear and tension or direct tension alone.

Worked Examples illustrating the design of connections using TCB Grade S10T are given in Appendix A. Examples with the bolts subject to externally applied tension are given in Appendix A, Examples 6 and 7.

2.3 Tightening

A lightweight electrical shear wrench has been developed to preload the bolts and a detailed description of the process can be found in Section 5. Although, the tightening procedure depends on torque, the design of the bolt with its break-neck and spline, is such that the specified minimum preloads in Section 3.2.2 will be realised when the spline shears off. Thus one of the erectors' tasks, preloading bolts, has been made simpler and more reliable with the use of these TCBs.

However, the pre-tightening stage of connection assembly is still required in order to ensure that all bolts and interfaces are bedded or "snug" before final tightening or preloading commences.

2.4 Handling

Like all precision made engineering products, the bolts assemblies should be stored and handled with care at all stages up to and including preloading, because any alteration or damage to the bolt may impair its efficiency.

2.5 Testing and inspection

In addition to any other client requirements at the time of ordering, it should be required that a minimum of five preloading tests be carried out per assembly lot. The results of these tests should comply with the values given in Table 7.1 of this document.

2.6 Calculations

The specified minimum preloads used in Section 3.2.2 have been verified by testing. These preloads are compatible with safe design to BS 5950-1:2000 and BS 5400-3:2000. However, the designer is advised to consult his client's brief or project specification for any limitations imposed.

2.7 Evaluation of TCB Grade S10T bolts by CTICM

Tension Control Bolts Ltd. commissioned a report[6] from CTICM to evaluate the performance of TCB Grade S10T. The report was prepared by Mr. Ivor Ryan of CTICM who is one of the French representatives on the European Committee on Bolting, CEN TC 185 WG6.

The principal conclusions of CTICM's report are:

1. TCB Grade S10T fasteners are suitable for use as a Grade 10.9 high-strength preloaded bolts.
2. TCB Grade S10T fasteners are suitable for use as a Grade 10.9 non-preloaded bolt.

Note: With the arrival of the new European Standard for high-strength preloaded bolts[7] and Eurocode 3[8], the design equations for obtaining the preload in the bolt will change from a UK perspective. However, the design equations for determining the slip resistance of a preloaded bolt in accordance with design standards BS 5950, BS 5400 or Eurocode 3 will remain unchanged.

3 DESIGN OF BOLTED CONNECTIONS

3.1 Design basis

For many practical reasons, bolts are installed in clearance holes in structural steelwork connections. These holes are normally 2 mm or 3 mm larger than the nominal bolt diameter used in the joint. Larger (oversized) holes or slotted holes can be used in some circumstances.

Most bolted connections transfer load 'in shear', i.e. the bolt axes are normal to the direction of the load to be transferred. A key choice facing the designer is whether the connection will allow or prevent slip between the joined components.

In a non-preloaded bolt arrangement, the applied force is transmitted by shear in the bolt shank and bearing between the shank of the bolt and the connected plies. In order for this load transfer mechanism to work, the plies must slip relative to each other as indicated in Figure 3.1. The advantages of non-preloaded bolting are that the bolts only require nominal tightening and the faying surfaces (the interfaces) do not have to be masked off for painting. However, there are many situations where this slippage is unacceptable.

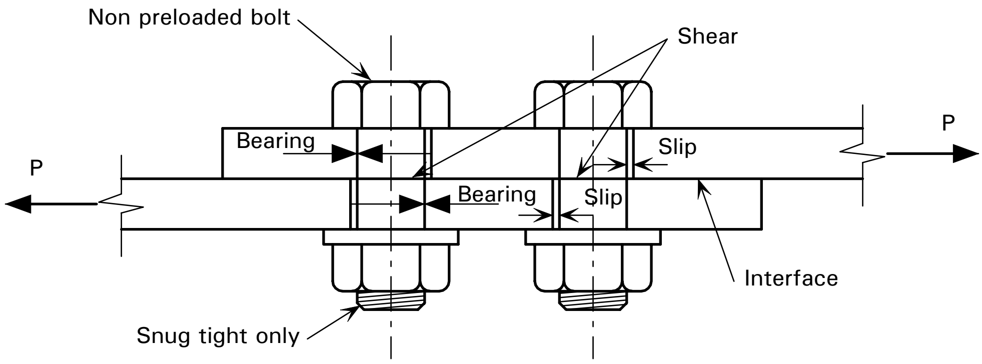


Figure 3.1 *Non-preloaded Bolt Arrangement*

Preloaded bolted joints, often-called friction grip joints transfer force quite differently. Frictional resistance between the contact surfaces of the plies transfers the load, as illustrated for a joint with TCBs, in Figure 3.2. This contact surface is known as an interface or faying surface. The frictional resistance is achieved by preloading the bolt in considerable tension, which clamps the plies together in compression, see Figure 3.3.

There are several methods to achieve the preload in the bolts and slip can be prevented even at the ultimate limit state, if required. The frictional resistance of the interface around the bolt depends on the level of preload in the bolts (compression on the faying surface) and the condition of the faying surfaces i.e. its slip factor or 'coefficient of friction'.

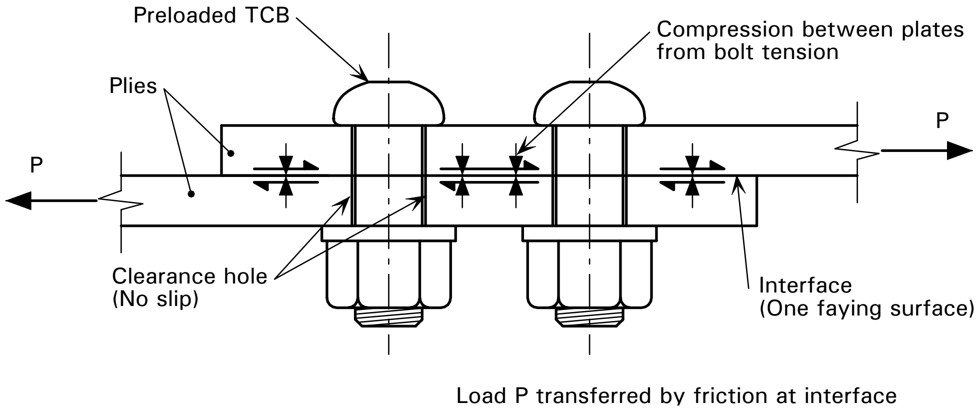


Figure 3.2 *Preloaded TCB Arrangement*

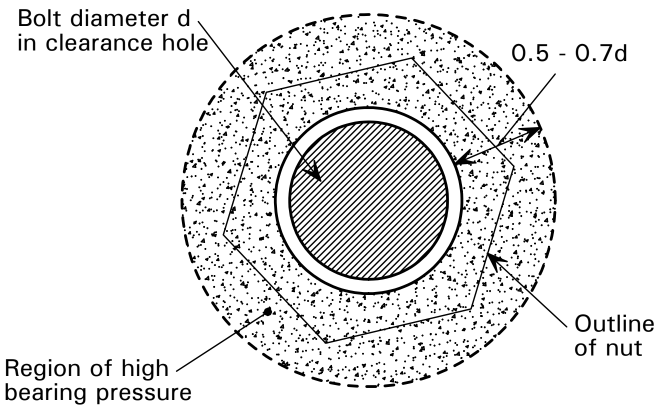


Figure 3.3 *Idealised distribution of bearing pressure at faying surface in a friction connection*

3.2 Design properties of bolts

3.2.1 Stress – strain characteristics

The key design properties for bolt material are illustrated in Figure 3.4. Grade S10T TCBs are grade 10.9 bolts and the minimum strengths specified in the Japanese Standard[9] are:

Minimum ultimate tensile strength 1000 N/mm²

Minimum yield strength (0.2% proof stress) 900 N/mm²

Both of these values may be used in design. In BS 5950-1 they are designated U_b and Y_b respectively and the minimum fracture load for a bolt is given by the expression:

Minimum Fracture Load $= U_b\, A_t$

Where A_t is the tensile stress area of the bolt

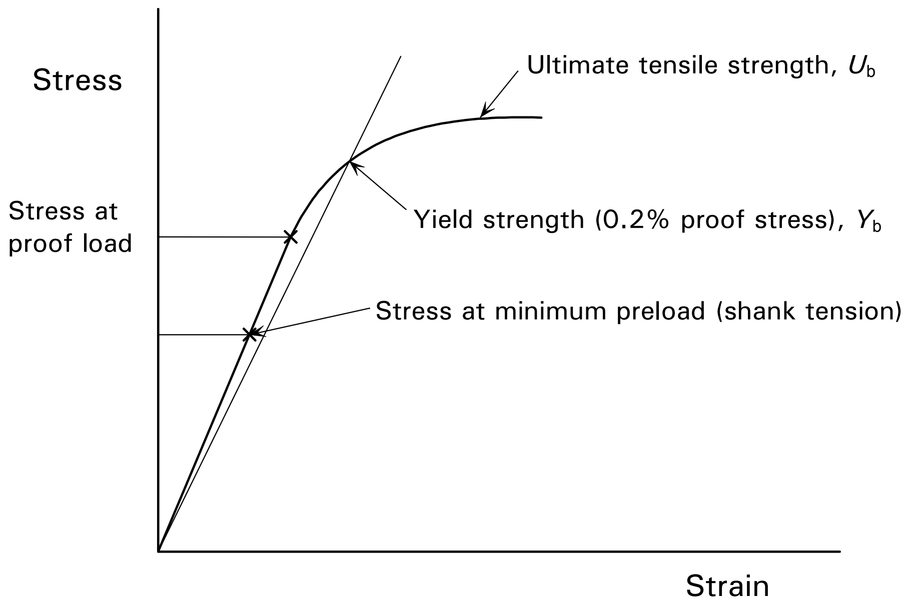


Figure 3.4 *Idealised Stress – Strain curve for preloaded bolts*

In addition, bolt assemblies are subject to proof load tests, where a specified tensile load is applied to the bolt and, upon removal of the load, the permanent extension of the bolt assembly must not exceed 12.5 microns. The stress at proof load is in effect the upper end of the linear part of the stress-strain curve for the bolt assembly. The value of 12.5 microns is so small that the permanent extension under proof load is negligible.

3.2.2 Specified minimum preloads (shank tension)

Values given in Standards

In BS 4604, the minimum shank tension for a preloaded bolt is specified in relation to the proof load and the proof load is specified in BS 4395 based on a particular stress level. For 'Part 1' bolts (i.e. bolts to BS 4395-1, tightened to BS 4604-1), which are effectively grade 8.8 bolts, the minimum shank tension is the same as the proof load. For Part 2 bolts (to BS 4395-2 and BS 4604-2), which are effectively grade 10.9 bolts, the minimum shank tension is specified as only 85% of the proof load. For Part 2 bolts the stress at proof load is given as 776 N/mm^2 and thus the minimum shank tension is based on 85% $\times$ 776 = 660 N/mm^2.

It should be noted though that the standards, BS 4395 and BS 4604, that support "Part 1" and "Part 2" bolts are almost 40 years old and represent the state of the art in bolt technology for the late 1960s.

The most recent international Standard for carbon and alloy steel fasteners, ISO 898-1 Table 3 specifies a slightly greater value for the proof load of a grade 10.9 bolt, 830 N/mm^2. Using this value and the 85% reduction factor in BS 4604-2, the minimum shank tension would be based on 85% $\times$ 830 = 706 N/mm^2.

Today, the internationally agreed trend is to base preload values on the two basic mechanical properties, the minimum ultimate tensile strength and the minimum yield strength. There are two commonly used alternatives:

Stress at specified minimum preload $= 0.8\ Y_b$ OR $= 0.7\ U_b$

For Grade S10T TCBs, which are grade 10.9 bolts with $Y_b = 900$ N/mm² and $U_b = 1000$ N/mm², these alternatives give values of 720 N/mm² and 700 N/mm² respectively.

Verified preload values for Grade S10T TCBs

As part of CTICM's investigations, a series of tests were carried out to measure the induced preload in Grade S10T TCBs in the installed condition, when tightened in accordance with the manufacturer's recommendations. One of the plates in each of the test specimens was deformed to simulate a lack-of-fit in steelwork connections and the bolts were preloaded in an unfavourable sequence. The preload in each bolt was measured after all the bolts had been installed in each test specimen, thereby accounting for any relaxation in preload owing to the lack-of-fit in the connection/specimen. All these measures were undertaken in order to replicate real steelwork conditions as far as possible.

CTICM's report concluded that, when tightened in accordance with the manufacturer's recommendations, the following specified minimum preloads may be used in design. These values should be used for designs in accordance with BS 5950 or BS 5400 for preloaded bolted connections.

Table 3.1 *Design values of minimum preload of TCB Grade S10T for use in design to BS 5950 and BS 5400*

Bolt	M12	M16	M20	M22	M24	M27	M30
Specified Minimum Preload P_o (kN)	61.0	113	176	218	254	330	404

These values are based on stress at preload of 720 N/mm²· . In BS 5400-3:2000, Clause 14.5.4.3 the specified minimum preload is called the Initial Load and has the notation F_o.

The CTICM report also considered design in accordance with Eurocode 3. In that Standard, the preload is based on a stress of $0.7U_b$ and so the preload values are slightly less. The design values are given in Table 3.2.

Table 3.2 *Design values of minimum preload of TCB Grade S10T for use in design to Eurocode 3*

Bolt	M12	M16	M20	M22	M24	M27	M30
Preloading Force $F_{p,C}$ (kN)	59.0	110	171.5	212.1	247.1	321.3	393.0

These values are based on stress at preload of 700 N/mm²

3.3 Design of connections with preloaded bolts

3.3.1 Design to BS 5950-1

Slip resistance

Clause 6.4.1 of BS 5950-1:2000 provides the designer with the following three design options for preloaded bolted connections:

a) a normal 'bearing type' connection

b) non-slip in service

c) non-slip under factored loads

Option a) is to design the joint as a bearing connection and the bolts as non-preloaded bolts, in accordance with Clause 6.3 (see Section 3.4 for guidance on design). In addition, Clause 6.4.2 provides two design resistance equations, which corresponds to options b) and c) in Clause 6.4.1.

Figure 3.5 shows an idealised load extension curve for a preloaded bolted connection for the type shown in the Figure. The important feature to note for a well-proportioned joint is that failure does not occur when the capacity of the frictional resistance is reached. At this stage the bolts slip into shear and bearing and the joint will continue to sustain increased applied loading while undergoing gross deformation until failure is reached, most likely by rupture of the plies. At slip, the load transfer mechanism changes from frictional resistance to shear and bearing.

Until slip takes place, the applied shear loading is carried by friction between the plies and the bolts have only direct tension stresses from the effect of the preload; they are not subject to shear stresses. After slip, the bolt is then subjected to applied shear and bearing stresses as well as tension stresses from any externally applied tension loading. As the bolt deforms under combined bending and shear, the preload is lost and the bolt behaves in the same way as a non-preloaded bolt.

A basic equation for the frictional resistance of a preloaded bolt up to slip maybe written as follows:

$$P_{sL} = \mu P_o$$

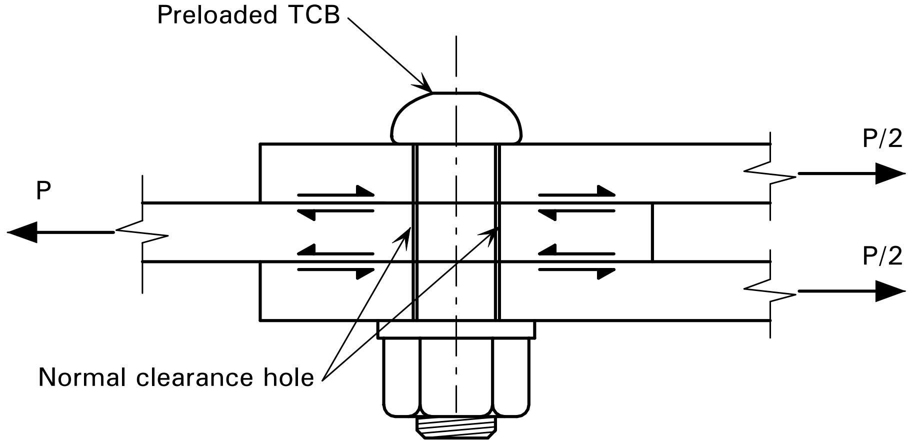
where:

P_{sL} is the slip resistance (per interface)

P_o is the minimum preload (shank tension)

μ is the slip factor (coefficient of friction).

For a connection with many bolts, the connection resistance is the product of P_{sL}, the number of bolts and the number of interfaces (= 2 for bolts in double shear).



Load P is applied perpendicular to longitudinal axis of the bolt - shear loading

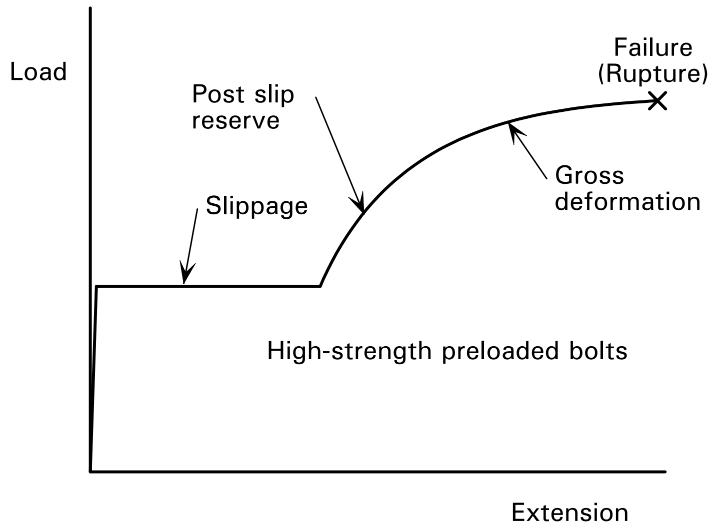


Figure 3.5 *Idealised load – extension curve for a well-proportioned preloaded bolted connection*

In Clause 6.4.2, this basic equation is modified as follows:

(For option b) $\quad P_{sL} = 1.1\ \mu\ K_s\ P_o$

and

(For option c) $\quad P_{sL} = 0.9\ \mu\ K_s\ P_o$

Where K_s is a factor that reduces the slip resistance for bolts in oversize or slotted holes. $K_s = 1.0$ for bolts in standard clearance holes.

If the number of bolts required to resist the Ultimate Limit State (ULS) loading on a joint is determined from the equation relating to option c), then the ULS loading will be realised before slip in the connection occurs. This is because the resistance per bolt is taken as less than the value that would be obtained from the basic equation and hence more bolts will be used in the joint to resist the same level of loading.

On the other hand, if the number of bolts required to resist the ULS loading on a joint is determined from the equation relating to option b), slip will occur before the ULS loading is realised. The joint slips into shear and bearing when the applied loading is between the Servicability Limit State (SLS) loading and the ULS loading. To ensure the ability of the joint to sustain the full ULS loading, there must be a post-slip capacity check, with the bolts in shear and bearing, in accordance with Clause 6.4.4. Clause 6.4.4 refers the designer to Clause 6.3.2. In these checks, the bearing strengths given by Clause 6.4.4 may be higher than for non-preloaded bolts, because deformation is not such a consideration since the connection does not slip until after the SLS load has been realised. As noted in Clause 6.4.1, the resistance to slip in service for a preloaded bolt is a serviceability criterion but for ease of use BS 5950 presents the design check, option b), in a modified form, suitable for checking under factored loads at the ULS.

The plies in **all** preloaded bolted connections should be checked for net section failure in tension, see Clause 4.6.1 or for compression. In addition, Clause 6.2.3 makes allowance for the effect of the net section on shear capacity, if required. These net section checks provide a well-proportioned joint, which leads to a ductile failure mode as shown in Figure 3.5.

The primary question facing the designer of preloaded bolted connections is which option, to use, b) or c)?

Option b), non-slip in service, is the option that corresponds to how HSFG bolts have been mainly used in orthodox building structures since the earliest days of HSFG joints. The equation for option b) is intended to achieve the same level of reliability as given by BS 4604. The design procedure in BS 4604 divides nominal slip resistance by a load factor of 1.4, for checking against (nominal) working load. In BS 5950 the typical 'average' factor at ULS on dead plus live load is 1.55; comparison of ULS load against nominal slip resistance times 1.1 achieves the same overall factor of approximately 1.4 ($1.55/1.4 \approx 1.1$).

Option c), non-slip under factored loads, is an option that is seldom used today. However, there are situations where the consequences of slip before ULS are so great that option c) should be used. An often-noted example is where a steelwork structure supports a sensitive piece of machinery but the designer should also consider using option c) for connections where slip or rotation would adversely affect the stability of the frame. In addition, the designer is strongly recommended to use option c) for connections using oversize or slotted holes, particularly, when one of the members joined is providing restraint to the other member(s). Option c) is always used for waisted-shank preloaded bolts and also hybrid connections where the load is shared between welds and preloaded bolts, see Clauses 6.1.1. and 6.4.2. of BS 5950-1:2000.

Resistance to combined tension and shear

Externally applied tension acting on a preloaded bolted connection reduces the clamping or compression force on the faying surface and hence tension reduces the frictional resistance of the connection. But the external tension does not change the tension in the bolt, unless it exceeds the preload. Clause 6.4.5, BS 5950-1:2000 gives design equations for combined shear and tension loading on preloaded bolts. Again, two cases exist, which correspond to options b) and c) of Clause 6.4.1. If the joint is only subject to applied tension, then by setting the applied shear, F_s to zero, the equations in Clause 6.4.5 may be used.

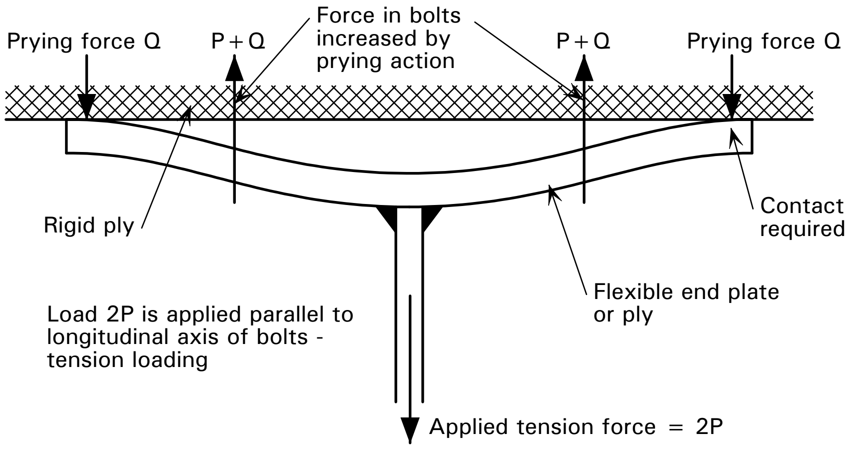


Figure 3.6 *Prying action on Tee bracket*

In addition, prying action in joints subject to applied tension is a major consideration in the design of preloaded bolted connections. Prying is a complex subject and although there has been much research on this topic, there is as yet no universally agreed method for the analysis of prying action in bolted joints subject to tension. Flexible plies deform or bend under tension loading producing contact or prying forces near the tips of end plates, which in turn leads to double curvature bending. Rigid plies deform much less, producing much less prying action and in fact, zero prying if single curvature bending is assumed. To some extent design becomes a trade off between thin flexible end plates with high bolt forces and thick rigid end plates with lower bolt forces. Apart from the flexural stiffness of the plies, the axial stiffness of the bolts also affects the magnitude of the prying in a joint. At SLS the value of the prying is dependent on whether the bolt is preloaded or not, however, at ULS the magnitude of the prying is independent of bolt type; see Figure 3.7. The bolts must carry these additional prying forces, if generated, in order to maintain equilibrium.

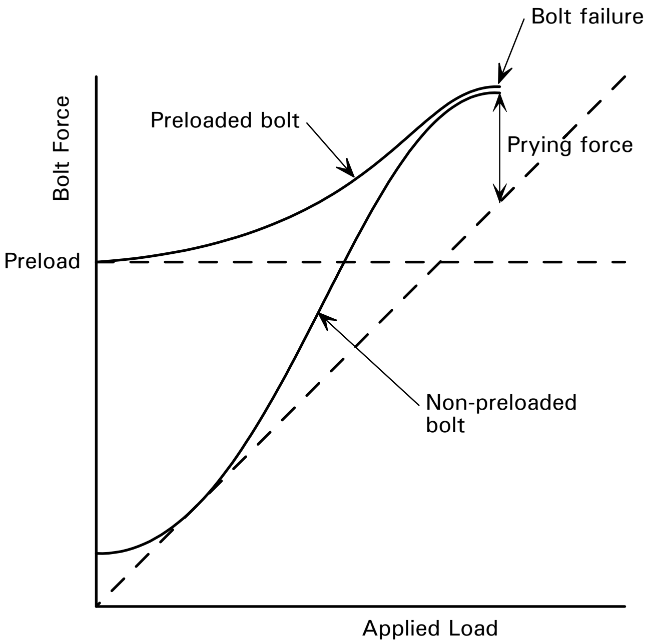


Figure 3.7 *Bolt force diagram for Tee bracket subject to prying (similar grade bolts)*

For these reasons, British steel design codes, for buildings, bridges and masts etc. have dealt with prying in many different ways. *Joints in steel construction, Moment connections* (P207)[10](for normal building structures, designed in accordance with BS 5950-1) is based on an early version of Annex J in Eurocode 3 (DD ENV 1993-1-1: 1992). Annex J has since been updated and incorporated into EN 1993-1-8 (*to be published in 2004*). It is likely that the EN 1993-1-8 approach will become the accepted method across Europe for dealing with prying in the coming years.

Clause 6.4.5 of BS 5950-1:2000 takes account of prying for preloaded bolted connections by using the "more exact method" in Clause 6.3.4.3 to determine the value of the prying force to be included in the total tension force on the bolt for use in the interaction equations. The "more exact method" makes the assumption that the prying force Q (given by plastic analysis) acts exactly at the tip of the end plate, if generated (see Figure 25, BS 5950-1:2000), although, the designer must determine the length to be used in calculating the bending resistance of the ply.

However, examples 5 and 6 in Appendix A have been based on References 12 and 13, which the reader should study. These earlier (elastic/plastic) conservative approaches to prying are compatible with BS 5950-1:2000 and do not require the length of yield line patterns to be determined in order to calculate the bending resistance of the plies.

If the option b) part of the combined shear and tension interaction check in Clause 6.4.5 is used, a post slip capacity check will also be required, in accordance with the more exact method in Clause 6.3.4.4.

3.3.2 Design to BS 5400-3

Section 14.5 of BS 5400-3:2000 gives the design equations to be used for determining the resistance capacity of bolted connections in bridge structures. In particular, the design engineer should note that non-preloaded bolts are not permitted in permanent main structural connections (Clause 14.5.3.1).

In bridge structures, joints are normally designed not to slip at SLS (Clause 14.5.4.1.2) but the bolts are allowed to slip into shear and bearing at ULS (Clause 14.5.4.1.1 b), which usually develops a greater strength than the friction capacity. In exceptional circumstances, the joint may be designed so that there is no slip at ULS (Clause 14.5.4.1.1a). Examples of the circumstances where joints are designed not to slip at ULS are:

- Preloaded bolts in oversized or slotted holes
- Where rigidity of the joint is required at ULS (e.g. sometimes at U-frame corners when a low value of flexibility f is required).
- Hybrid connections where the load resistance is shared between welds and preloaded bolts

3.3.3 Fatigue Design

When preloaded bolted joints are subjected to fatigue loading, they should be checked against the provisions of either BS 7608: 1993 or BS 5400-10:1980, as appropriate.

3.4 Non-preloaded bolted connections (BS 5950)

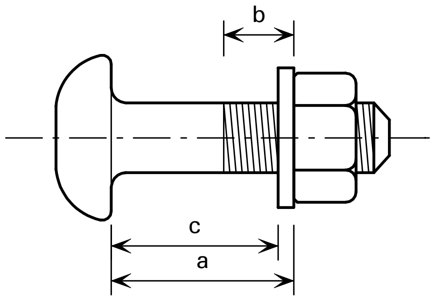
CTICM's report recommended that TCBs, Grade S10T, are suitable for use as Grade 10.9 non-preloaded bolts; thus they may be designed according to the provisions of Section 6.3 of BS 5950-1:2000. Non-preloaded bolts need only be fully tightened by hand using spanners (see Clause 6.1.8, NSSS[4]); although, for TCBs this means that the spline would remain on the bolt in the permanent condition. Non-preloaded bolted connections or bearing connections do not require the contact surfaces to be masked off or protected since the load is not transferred by friction but by shear and bearing (slip is permitted). Hence the cost and time of preparing the contact surfaces can be saved and the whole of the steelwork painted etc., as for any normal steelwork project using non-preloaded bolted connections.

If, for whatever reason, it is unacceptable to leave the splines on the bolts then the bolts must be preloaded or tightened in accordance with the manufacturers' recommendations. This is acceptable for non-preloaded bolted connections but the designer should note that if the contact surfaces are painted, in order to save the time and cost of masking them off, the joint will have a low frictional resistance capacity, because the slip factor will be in the order of 0.2. In many situations this will not be a concern, because the connection will slip into bearing or be supported in bearing under self-weight during erection. However, in some cases the frictional resistance of the joint will only be exceeded during construction of the project and a loud noise may occur as the joint slips into bearing. The tension stresses in the bolt from the preloading are lost at slip and hence should not be combined with the applied shear and bearing stresses although the stresses from any applied tension must be taken into account.

If the faying surfaces are not painted, then the slip factor may be high, in the order of 0.5, and a joint with preloaded bolts will have a high frictional resistance that may not slip until considerable loading is applied. For this reason it is recommended that unpainted contact surfaces be avoided when TCBs, Grade S10T, are being designed as non-preloaded bolts but the bolts are being preloaded in order to remove the spline.

3.5 Ductility and bolt lengths

To ensure adequate ductility of bolts, BS 5950-2[1] (Table 3) gives minimum lengths of thread (in addition to the thread run-out) that should exist in the stressed length of a bolt. For a Grade S10T TCB, which has a greater ductility than bolts to BSI standards, slightly modified limits may be used; these are given in Table 3.3, for the various loading conditions, in terms of a number of thread pitches of the bolt.



a = stressed length

b = threaded portion in stressed length

c = grip length (sum of ply thickness)

Figure 3.8 *TCB, Grade S10T*

Table 3.3 *Minimum threaded portion in stressed length of Grade S10T TCBs*

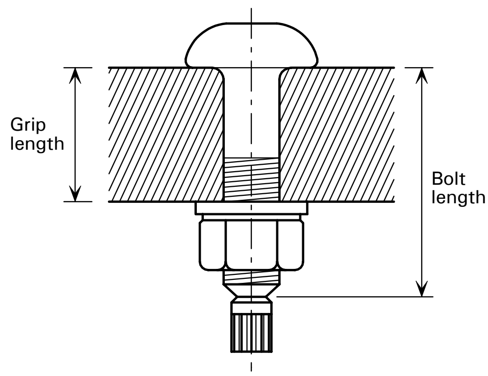
Loading condition	Number of clear threads
Non-preloaded in shear only	1
Non-preloaded otherwise	3
Preloaded	3

These minimum threaded portions are the means to ensure that Grade S10T bolts have sufficient ductility to be used safely in normal structural connections. Further, the designer should be careful when specifying large diameter grade S10T bolts in conjunction with very short grip lengths, since the minimum threaded portion required may exceed the grip length. Therefore, a good rule of thumb is to maintain the minimum ply thickness in a connection to greater than or equal to half the nominal bolt diameter used, where possible.

For ordering purposes, the required bolt length may be determined from the following table. Reference may also be made to TCB Ltd's brochures.

Table 3.4 *Bolt length allowance to be added to grip length*

Normal size of threads	To determine required bolt length, add to grip length
MM	MM
M 12	20
M 16	25
M 20	30
M 22	35
M 24	40
M 27	45
M 30	50



3.6 Detailing and other components

Reference should be made to the project design standards in order to determine the resistance of other components, plates and welds etc. used in connections.

End and edge distances for TCBs, Grade S10T, as well as bolt spacing requirements should be determined in accordance with the project design standards.

See Appendix B for details of the shear wrenches when considering access requirements. Where special access requirements arise and other shear wrenches may be of help, information should be sought from Tension Control Bolts Ltd.

3.7 Greenkote™

Tension Control Bolts Ltd. has its own sophisticated metal treatment plant producing surface treatment, Greenkote PM1. Greenkote is an innovative Thermo-Chemical Surface Modification (TCSM) technology giving excellent corrosion resistance properties that exceed the requirements of BS EN ISO 1461. This anti-corrosion coating is produced in an environmentally friendly plant resulting in no waste solids; liquids or gasses and giving totally uniform surface coating. TCB Ltd also offer galvanizing and electro-galvanizing in accordance with BS 7371.

TCBs are then subjected to additional processing in order that the preload, when installed, meets the specified minimum preload requirements of Section 3.2.2 (Tables 3.1 and 3.2). Table 7.1 sets out the requirements for the five preload tests required at the time of ordering.

4 MANUFACTURING SPECIFICATIONS

4.1 Standards

TCBs, Grade S10T, are manufactured in accordance with the following two Japanese Standards and the properties and dimensions outlined in Sections 4.2 to 4.8 inclusive are taken from these standards.

JIS B 1186 – 1995[9]. *Sets of high strength hexagon bolt, hexagon nut and plain washers for friction grip joints*. JSA 1995 (Japanese Standards Association)

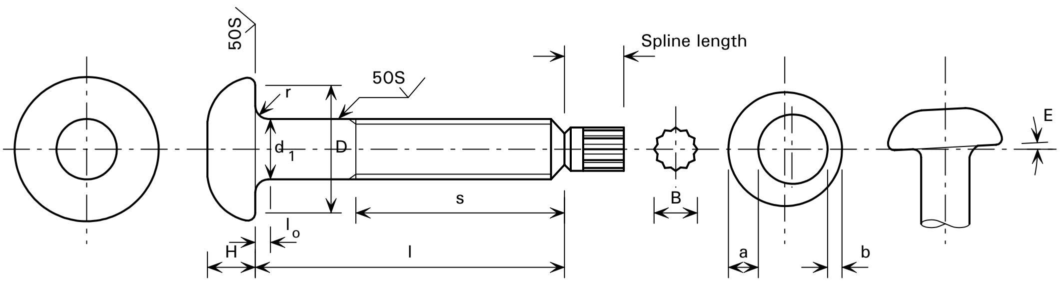
JSS II – 09 – 1996[11]. *Sets of torshear type high strength bolt, hexagon nut and plain washer for structural joints*. SSCJ 1981 (Society of Steel Construction of Japan)

Note: A set is a bolt assembly comprising a matching bolt, nut and washer for a strength grade and bolt type.

WARNING: The dimensions and properties given below relate only to Grade S10T tension control bolts, as manufactured by TCB Ltd. They should not be used for any other tension control bolts.

4.2 Dimensions of tension control bolts Grade S1OT

Grade S10T TCBs are manufactured in accordance with the dimensions and tolerances given in Table 4.1 and Table 4.2.



Note: The measuring point for d_1 should be $l_o = d_1/4$

Figure 4.1 *Tension control bolts*

Table 4.1 *Dimensions and tolerances of tension control bolts*

<table>
<tr><th rowspan="2">Nominal size of threads</th><th colspan="2">d_t</th><th colspan="2">*H*</th><th>*D*</th><th colspan="2">B</th><th rowspan="2">r</th><th>a-b</th><th>E</th><th colspan="2">*s*</th></tr>
<tr><th>Basic dimension</th><th>Tolerance</th><th>Basic dimension</th><th>Tolerance</th><th>min</th><th>Basic dimension</th><th>Tolerance</th><th>Max.</th><th>Max.</th><th>Basic dimension</th><th>Tolerance</th></tr>
<tr><td>M 12</td><td>12</td><td rowspan="2">+0.7
-0.2</td><td>8</td><td rowspan="2">±0.8</td><td>21</td><td>7.7</td><td rowspan="7">±0.3</td><td>0.8-1.6</td><td>0.7</td><td rowspan="7">1°</td><td>25</td><td rowspan="2">+5
0</td></tr>
<tr><td>M 16</td><td>16</td><td>10</td><td>26</td><td>11.3</td><td rowspan="3">1.2-2.0</td><td>0.8</td><td>30</td></tr>
<tr><td>M 20</td><td>20</td><td rowspan="5">+0.8
-0.4</td><td>13</td><td rowspan="4">±0.9</td><td>33</td><td>14.1</td><td>0.9</td><td>35</td><td rowspan="5">+6
0</td></tr>
<tr><td>M 22</td><td>22</td><td>14</td><td>37</td><td>15.4</td><td>1.1</td><td>40</td></tr>
<tr><td>M 24</td><td>24</td><td>15</td><td>41</td><td>16.8</td><td rowspan="2">1.6-2.4</td><td>1.2</td><td>45</td></tr>
<tr><td>M 27</td><td>27</td><td>17</td><td>47</td><td>19.0</td><td>1.3</td><td>50</td></tr>
<tr><td>M30</td><td>30</td><td>19</td><td>±1.0</td><td>53</td><td>21.1</td><td>2.0-2.8</td><td>1.4</td><td>55</td></tr>
</table>

Dimensions in millimetres

Table 4.2 *Tolerances on nominal length*

Nominal bolt length l	Tolerance
30 up to 50	±1.0
55 up to 120	±1.4
125 up to 180	±1.8

Dimensions in millimetres

Table 4.3 *Design parameters*

Bolt	M 12	M 16	M 20	M 22	M 24	M 27	M 30
Nominal Area mm^2	113	201	314	380	452	573	707
Tensile Stress Area (A_t) mm^2	84.3	157	245	303	353	459	561
Thread Pitch mm	1.75	2.00	2.50	2.50	3.00	3.00	3.50
Spline Lengths mm	13	15	18	19	20	22	24

4.3 Dimensions of hexagon nuts

Heavy hexagon nuts for S10T TCBs are manufactured in accordance with the dimensions and tolerances given in Table 4.4.

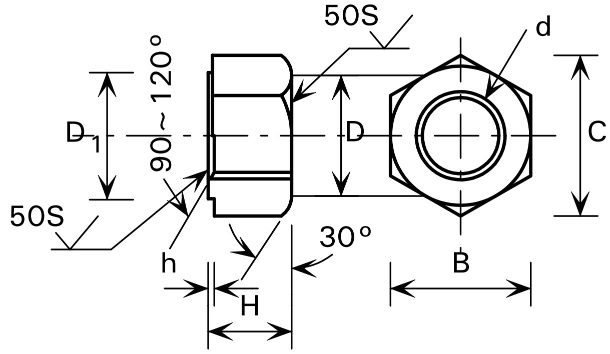


Figure 4.2 *Hexagon nuts*

Table 4.4 *Dimensions and tolerances of hexagon nuts*

Nominal size of threads *(d)*	Outside dia. external thread	***H***		***B***		***C***	***D***	***D***	***h***
		Basic dimension	**Tolerance**	**Basic dimension**	**Tolerance**	**Approx**	**Approx**	**Min**	
M 12	12	12	±0.35	22	0 -0.8	25.4	21	20.2	0.4 -0.8
M 16	16	16		27		31.2	25	25	
M 20	20	20	±0.4	32	0 -1	37	30	29	
M 22	22	22		36		41.6	34	33	
M 24	24	24		41		47.3	39	38	
M 27	27	27		46		53.1	44	43	
M 30	30	30		50		57.7	48	47	

Dimensions in millimetres

4.4 Dimensions of circular hardened washers

Washers for TCB Grade S10T are manufactured to the dimensions given in Table 4.5.

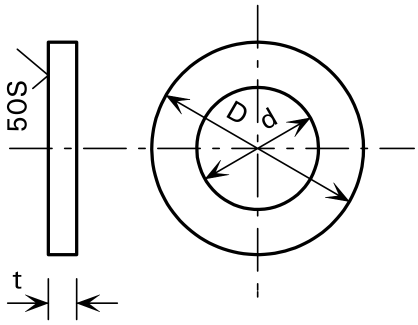


Figure 4.3 *Circular hardened washers*

Table 4.5 *Dimensions and tolerances of circular hardened washers*

<table>
<tr><th rowspan="2">Nominal size of washers</th><th colspan="2">d</th><th colspan="2">D</th><th colspan="2">t</th></tr>
<tr><th>Basic dimension</th><th>Tolerance</th><th>Basic dimension</th><th>Tolerance</th><th>Basic dimension</th><th>Tolerance</th></tr>
<tr><td>M 12</td><td>13</td><td rowspan="2">+0.7
0</td><td>26</td><td>0
−0.8</td><td>3.2</td><td>±0.7</td></tr>
<tr><td>M 16</td><td>17</td><td>32</td><td rowspan="5">0
−1</td><td rowspan="2">4.5</td><td rowspan="2">±0.5</td></tr>
<tr><td>M 20</td><td>21</td><td rowspan="4">+0.8
0</td><td>40</td></tr>
<tr><td>M 22</td><td>23</td><td>44</td><td rowspan="3">6</td><td rowspan="4">±0.7</td></tr>
<tr><td>M 24</td><td>25</td><td>48</td></tr>
<tr><td>M 27</td><td>28</td><td>56</td></tr>
<tr><td>M 30</td><td>31</td><td>+1.0
0</td><td>60</td><td>0
−1.2</td><td>8</td></tr>
</table>

Dimensions in millimetres

4.5 Material properties

TCBs Grade S10T are manufactured to the material specification given in JIS B 1186[9]. The values given in Table 2 of that specification are presented in Table 4.6.

Table 4.6 *TCB Grade S10T material properties, (based on Table 2, JIS B 1186 – 1995)*

Grade of bolt according to mechanical properties	Proof strength N/mm^2	Tensile strength N/mm^2	Elongation %	Reduction of area %
S 10T	900 min.	1000-1200	14 min.	40 min.

Table 2, JIS B 1186: 1995 gives the proof strength for Grade S10T as 900 N/mm^2 i.e. the stress at 0.2% permanent strain is taken as the yield strength of the bolt material. JIS B 1186: 1995 does not require a proof load test as understood in the UK and hence for the purposes of this design guide, the proof strength relating to a permanent extension of a bolt assembly (not exceeding 12.5 microns) when the proof load has been removed should be taken as 830 N/mm^2. This is the value in Table 3, EN ISO 898-1:1999 for Grade 10.9 bolts and in order to substantiate this value a number of proof load tests and wedge tests were carried out on TCBs, Grade S10T, in accordance with EN ISO 898-1:1999. Test results are shown in Tables 4.7 and 4.8. The proof loads in these tests were derived from the assumed proof strength of 830 N/mm^2 and all the permanent extensions were less than 12.5 microns as follows:

Table 4.7 *Proof load test result for TCBs, Grade S10T, – EN ISO 898-1:1999*

Bolt Size	M16 × 80	M20 × 85	M22 × 95	M24 × 100	M30 × 180
No. 1	+ 1 μm	+ 1 μm	+ 2 μm	+ 1 μm	+ 6 μm
No. 2	+ 3 μm	+ 5 μm	+4 μm	+ 2 μm	+ 5 μm
No. 3	+ 3 μm	+ 5 μm	+ 2 μm	+5 μm	+ 2 μm
Average	+ 2.3 μm	+ 3.7 μm	+ 2.7 μm	+ 2.7 μm	+ 4.3 μm

Table 4.8 *Wedge test result for TCBs, Grade S10T, - EN ISO 898-1:1999*

Bolt Size	M16 × 80	M20 × 85	M22 × 95	M24 × 100	M30 × 180
Spec (Min.)	157 kN	245 kN	303 kN	353 kN	561 kN
No. 1	173.5	278.1	349.6	396.2	639.6
No. 2	171.2	275.5	351.2	398.7	639.9
No. 3	173.4	277.2	345.7	396.2	635.9
Average	172.7	277.0	348.8	397.0	638.4

(See Section 4.6 for minimum breaking loads i.e. Spec (Min.)).

In JIS B 1186: 1995 the 14% elongation is measured over a gauge length of 3.54 diameters up to a maximum length of 50 mm and is equivalent to 12% elongation over a normal European gauge length of 5 diameters or 5.65 $\sqrt{S_o}$. The conversion is done using the Oliver formula from BS EN ISO 2566-1:1999. EN ISO 898-1:1999, Table 3 requires a minimum elongation of 9% for Grade 10.9 bolts and hence S10T material exceeds the minimum requirements with 12% and in fact, S10T material satisfies the ductility requirements for Grade 8.8 bolts i.e. 12% - EN ISO 898-1:1999, Table 3. TCBs, Grade S10T, are manufactured with an additional chemical element, Boron, added which results in a high-strength steel, Grade S10T.

In addition, ductility results in the order of 19 to 21% (min. 14%) are often recorded in quality control tests carried out to the Japanese standard JIS B 1186: 1995. Moreover, tests performed by Prof. Gunter Valtinat of the Technische Universitat Hamburg-Harburg have shown that preloaded TCBs, Grade S10T, can sustain substantial nut rotation after preloading before bolt rupture occurs in the threaded portion of the shank.

4.6 Mechanical properties of bolts nuts, and washers

Table 4.9 *Minimum breaking loads for full size TCBs Grade S10T (Based on Table 3, JIS B 1186-1995)*

Grade of Bolt	Minimum Tensile (breaking) load (kN)							Hardness
	Nominal size of thread							
	M 12	M 16	M 20	M 22	M 24	M 27	M 30	
S10T	85	157	245	303	353	459	561	H_RC 27-38

Table 4.10 *Mechanical properties of nuts (Based on Table 4, JIS B 1186-1995)*

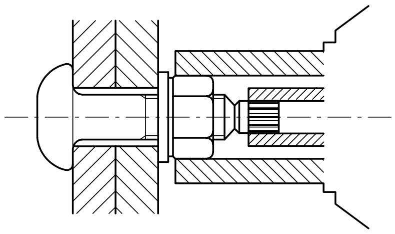
Grade of nut according to mechanical properties	Hardness		Guaranteed Load
	min.	max.	
S10T	H_RB 95	H_RC 35	Same as tensile (breaking) load (min.) of bolt

Table 4.11 *Washer hardness (Based on Table 5, JIS B 1186-1995)*

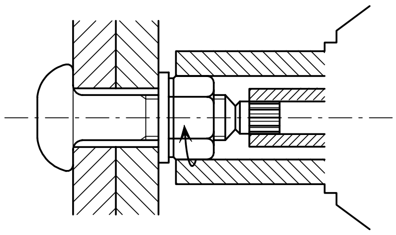
Grade of washer according to mechanical properties	Hardness
F35	H_RC 35-45

5 INSTALLATION AND PRELOADING

1. Ensure that the connection is properly fitted and assembled and in addition, that all the bolts in the joint are snug tight before commencing preloading – see Section 6.5.3

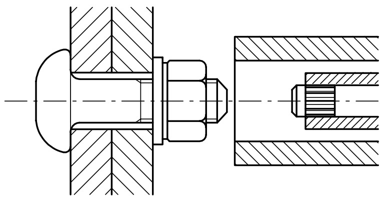
2. 

   Slide the inner socket over the bolt spline and the outer socket over the nut.

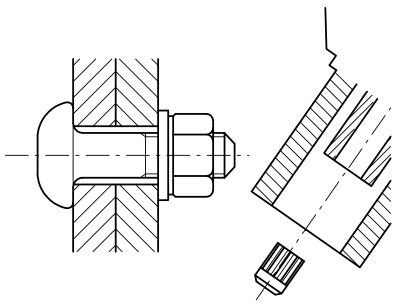
3. 

   Switch on the electric power supply to the wrench. The wrench applies a torque to the nut, via the outer socket, and reacts against the spline, via the inner socket. The nut rotates, while the bolt does not turn. When the torque reaches a sufficiently high level the spline shears off at the break neck (or grove).

Note: The break-neck, between the spline and the threads is sized so that the spline will not shear off until the correct or minimum torque has been applied and hence the preload has been induced into the shank of the bolt. Because the applied torque and reaction in preloading the bolt takes place outside and to one side of the grip length, no torsional shear stresses are induced into the shank of the bolt during the tightening process. Tests on tension control bolts[14] have confirmed that the tightening procedure does not produce shear stresses in the shank of the bolt.

4. 

   When the spline has sheared off pull back on the wrench until the outer socket is no longer engaging the nut.

5. 

   The bolt spline is retained by the inner socket and can be discarded by engaging the small trigger on the wrench handle.

6. To inspect the bolt – after tightening or in the future – merely check that the spline has been sheared off

6 REVIEW

6.1 Historical review of preloaded bolts

In the early 1950s, high strength friction grip (HSFG) bolts in clearance holes and welding replaced riveting, which had been the primary method of joining structural members into frameworks for most of the preceding 200 years. Today, rivets are seldom if ever used and HSFG bolts are known as preloaded bolts.

Various types of “ordinary” or “black” bolts were also used in clearance holes for joining frameworks together and these “ordinary” bolts have evolved into what is known today as non-preloaded bolts. Turned and fitted bolts are a special type of non-preloaded bolt where there is a close fit between the bolt shank and hole.

In simplistic terms, rivets or turned and fitted bolts were used where slip in a structural connection was unacceptable and ordinary bolts were used where slip was acceptable. Rivets were the most popular option and were often used irrespective of the connection type.

In the 1930s and 40s the advances in welding technology and the production of high strength steels for bolts allowed a seminal change to take place in the means of joining structural members together. It quickly became common practice to use HSFG bolted joints for connections assembled on site and to use welding for connections made in the fabrication shop. However, preloaded bolted connections can be made with success in the fabrication shop as well as on site.

With the choice between high strength friction grip bolts on the one hand and (low-strength) ordinary bolts on the other hand, the practice of using HSFG bolts in most connections continued until the early 1980s. The emergence of higher strength (Grade 8.8) ordinary bolts began in the 1970s and today the choice facing the structural designer is between the use of preloaded and non-preloaded bolts, both high-strength, depending on several factors but primarily on whether slip is critical.

6.2 Frictional resistance of preloaded bolts

For preloaded bolts in normal clearance holes, the frictional resistance, often called the slip resistance, is governed by three main factors: preload in the bolt; number of interfaces or faying surfaces between the plies; and the coefficient of friction for the faying surfaces, usually called the slip factor. The frictional resistance of a preloaded bolt is given by the following equation:

Frictional resistance per bolt = No of interfaces × Slip Factor × Preload

Hence the total resistance of a simple structural connection is given by the following equation:

No of bolts in the connection × Frictional resistance per bolt.

It is assumed in the above equation that all the bolts in the connection share the resistance to the design loading equally. This assumption is made in BS 5950-1:2000 but BS 5400-3:2000 makes a specific allowance for long joint effects.

Obviously, other failure modes in the connection must also be checked, net Section failure of the plies for example. Moreover, additional reduction factors could be added to this equation in order to account for other effects if necessary i.e., oversize holes, long joints etc.

6.3 Use of preloaded bolts

The primary advantage of using a friction grip connection (Figure 6.1) is that slip is prevented. Various clauses in design standards, Clause 6.1.7 of BS 5950-1:2000 for example, reminds designers that special consideration is required when connections are subject to vibrations, load reversal or fatigue, etc. Hence, there are several reasons for using preloaded bolts in connections outlined below.

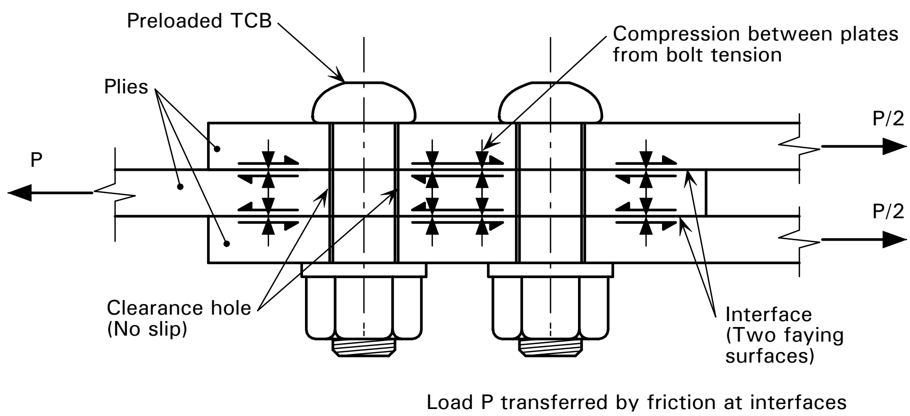


Figure 6.1 *Preloaded bolted connection: Two interfaces (shown with TCBs)*

6.3.2 Fatigue

In structures where fatigue is a design consideration, the use of preloaded bolted connections is recommended. The high level of preload means that the tension in the bolt does not vary significantly, provided that the plies are stiff and truly in contact at the bolt. For connections subjected to static loading only, the location of contact area on the faying surface is not as critical.

6.3.3 Vibration

Continued vibration has been known to lead to non-preloaded bolt assemblies becoming loose. Preloaded bolts may be used when vibration is a concern. However, it should be noted that nuts working loose due to vibration is not normally a consideration in orthodox building structures. Concerns over vibration lead many designers to use preloaded bolts in the end details of hanger members, even though the connection is often not subjected to shear but only direct tension. TCBs, like all preloaded bolts, do not loosen when subjected to vibrations, if installed correctly.

6.3.4 Load reversal

When load reversal occurs (excluding reversal solely from wind loading) the possibility of slip in the connections (as the clearance holes allow movement to and fro) should be prevented. Significant reversal may take place in structures supporting moving loads such as cranes. Preloaded bolts are recommended in these situations.

6.3.5 Dimensional stability

Even if load reversal is not possible, it may be important to eliminate slip in connections. Examples include splices in moment-resisting members, where slip in the cover plate may lead to additional deflections in the member and an unsightly kink. In some situations, accumulated slip in a number of bolted connections may lead to additional deflection of the overall structure. To prevent additional deflections from accumulated connection slippage, connections in shallow-slope trusses and vertical bracing connections in tall, multi-storey buildings are often made with preloaded bolts.

6.3.6 Overseas practice

The custom and practice of steel construction in other countries has often developed in ways that appear strange in comparison to British practice. Thus it may be necessary to use preloaded bolts on overseas projects or for overseas clients in ways that appear unfamiliar. The most common example is where only preloaded bolts are used irrespective of the structural form, connection type or consequence of bolt slip, since it is claimed that preloaded bolts add to the overall stiffness of the structure in preventing slip.

6.4 Tightening of preloaded bolts

The adequacy of any friction grip – slip resistance – in a joint depends on two main aspects, the condition of the faying surface and the preload in the bolt. Thus it is very important to ensure that the intended level of preload has been achieved, particularly where the purpose is to prevent slip. Over the years many different methods have evolved to ensure that the correct preload has been installed in the bolt:

1. Torque control method
2. Turn-of-the-nut method
3. Combined method (Part Turn / Part Torque)
4. Load indicating washers
5. Load indicating bolts (No longer manufactured)
6. Torshear bolts
7. Tension control bolts

In the early years of preloaded bolts, the control of the preload was ensured by the first two methods or by method 3 (mainly used outside the UK – a combination of methods 1 and 2). Although these methods have been and continue to be used very successfully, they all require a high level of skill and judgement on the part of the steel erector on site or in the fabrication shop. For a full treatment of these methods, reference should be made to the various technical literature and design standards on friction grip bolting.

To avoid reliance on operator skill, it is not surprising that bolt manufacturers have sought to introduce various ways that put the onus on the bolt itself to indicate that the required preload is obtained. Methods 4, 5, 6 and 7 are the results of these endeavours.

Methods 4 and 5 rely on protrusions on a special washer or on the underside of the bolt head. These protrusions create a gap prior to preloading in the installed assembly. On tightening the bolt, the gap reduces as the protrusions depress and when the specified gap is obtained the bolt tension will not be less than the required minimum. Gaps may be measured with a feeler gauge but, with some practice, can be judged by eye with sufficient accuracy. Again, both methods have been used successfully, but both methods still require skilled steel erectors. Reference should be made to technical literature for a full description.

Method 6, the Torshear bolt, was developed by GKN in the UK and was a forerunner of the present day Tension Control Bolt. In the UK the Torshear bolt was largely superseded by methods 4 and 5 because of various shortcomings. However, the basic technology was taken up in Japan where it developed into today's Tension Control Bolt. The pneumatic Torshear Tool was replaced by a lightweight electrical shear wrench; the bolt material became higher-grade, high-ductile steel and the bolt dimensions evolved to those given in Section 4. The concept then spread to North America, where Tension Control Bolts for Grades A325 and A490 bolts are commonly used today.

Over the last 20 years, method 7 – Tension Control Bolts – has gained worldwide popularity for one simple reason, it makes the task of the steel erector in installing, preloading and checking the bolt on site or in the fabrication shop much simpler. The tension control bolt is extended beyond the length required: the extension (spline) is separated from the main bolt by a break-neck or groove, which is machined to a predetermined depth to ensure that the extension (spline) shears off when the correct preload is achieved. Special lightweight electrical shear wrenches have been developed to achieve the shearing of the spline and tests have shown that no torsional shear stresses are induced into the shank of the bolt during the tightening process. Only axial load or pure tension is induced into the shank of the bolt during preloading. Refer to Section 5 for a description of the installation process. The bolt indicates to the steel erector when the required preload has been achieved and this makes one of the erector's tasks, preloading the bolts, simpler and quicker to perform.

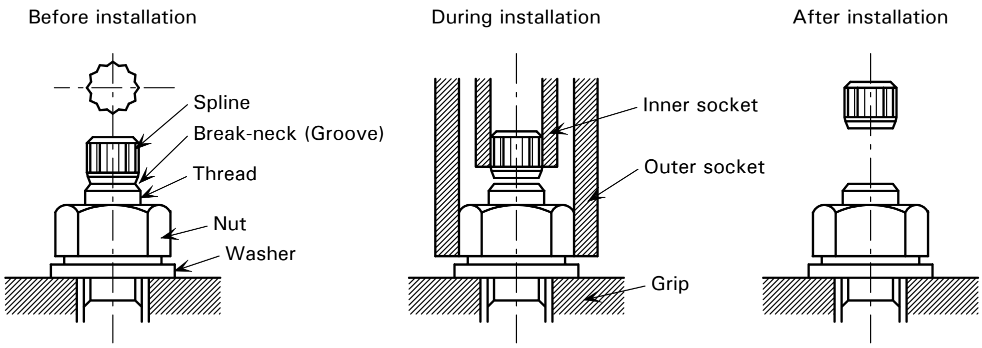


Figure 6.2 *Preloading sequence*

The purpose of tightening or preloading a bolt in a controlled manner is to induce at least a minimum level of tension in the shank of the bolt on which design calculations can be based. This induced tension is now called a preload but was traditionally called the minimum shank tension in the UK. Design standards give a minimum value of preload or minimum shank tension that can be safely used in design calculations; a successful tightening procedure will normally induce a tension in the shank of the bolt greater than that in the design standard. All of the above tightening procedures, if applied correctly, will achieve these objectives but the tension control bolt has the great advantage of simplicity and quickness when it comes to installation.

6.5 Practical aspects

6.5.1 Faying surfaces and slip factors

After the level of preload induced in the shank of the bolt by tightening, the coefficient of friction or slip factor of the faying surface is the next most important parameter affecting the frictional resistance of a preloaded bolted connection. The slip factor is dependent on the condition of the faying surface and its surface treatment (i.e. unpainted, painted or zinc spray etc). The value of the slip factor can vary from 0.1 to 0.5, depending on the surface treatment and hence it is imperative that the correct value is used in the structural calculations.

For steelwork used in internal conditions[11], the faying surfaces are mostly shot blasted and left unpainted, because this gives a high slip factor of the order of 0.5. Therefore the contact or faying surfaces must be masked off after shot blasting of the steelwork and prior to its painting. This can be a time consuming operation in the fabrication shop and the masking off must remain in place until the connection is assembled on site in order to inhibit rusting of the faying surface as well as offering protection during transport and erection. When the connection has been made on site and all the bolts preloaded, the area around the connection must be made good with the paint system or surface treatment system for the steelwork. It is also necessary to apply these corrosion measures to the rough surface left at the break neck when the spline has been sheared off. If for any reason the faying surface becomes painted in the fabrication shop or rusted on site, then the slip factor for the joint will almost certainly be lower than the value assumed in the structural calculations and the connection may be unsafe. For this reason, accidentally painted or significantly rusted faying surfaces are normally re-blasted before the connection is made on site.

In recent years, new paint systems have emerged for use on faying surfaces that give very high slip factors but as yet they are seldom used. If it is proposed to use one of these special paint systems, the slip factor for the faying surface should be established by tests.

Sometimes, the faying surfaces in a preloaded joint are painted with normal paint systems, especially in connections subjected to direct tension only where shear or slip is not a primary consideration or if the designer takes account of the lower slip factor associated with painted surfaces. Where the corrosion protection system is applied to the faying surfaces, the appropriate slip factor must be used in the structural calculations, especially since the value is often much less than 0.5 used for shot blasted surfaces.

The slip factor for the faying surface can be determined from standard tests as described in BS 4604; see example 7. The slip factor is determined from the minimum applied load that causes a displacement of 0.1 mm from 3 standard test specimens. However, for common surface conditions, it is usually not necessary for the designer to determine the slip factor directly, reference can be made to Table 35 in BS 5950-1:2000 or to Clause 14.5.4.4 in BS 5400-3:2000.

6.5.2 Hardened washers

Since the earliest days of friction grip joints, the high-strength bolt has been supplied with a hardened washer between the rotated part (usually the nut) and the structural component. For Tension Control Bolts the hardened washer is always placed between the nut and the plies i.e. between the ply and the item (nut) that rotates during tightening. In preloaded bolts only about 10% of the torque used in tightening produces tension in the shank of the bolt, the remaining 90% overcomes the friction between the threads of the nut and shank as well as the friction between the hardened washer and the face of the nut as it rotates. In order to control and limit the friction under the face of the nut a hardened washer with known friction characteristics is used. If the bolt assembly is used without a hardened washer and the nut is rotated directly against the ply, there is no control over this portion of the friction. It has been known for high-strength nuts to dig into soft plies, galling the surface and thereby increasing the tightening torque required, which can lead to locking up of the nut and bolt during tightening and/or under tightened bolts. Thus it is very important that the supplied hardened washer is used and installed under the nut and not under the head in order to ensure adequate joints. This is made easier when bolt assemblies are supplied to site as complete sets.

6.5.3 Joint assembly

The first issue is that all the plies have to be aligned together for the insertion of the bolts in clearance holes. This is usually not a problem for small or medium size joints, that is, the vast majority of connections. However, it is not uncommon to use a drift-pin or podger spanner to align the plies in large connections, owing to the size and weight of the plates. The plies should be aligned with sufficient accuracy to allow the free insertion of all bolts in normal clearance holes by hand. Most specifications allow the drifting of holes without distorting the plies to achieve bolt insertion but driving of bolts by hammering should never be permitted, since it may damage the threads.

When the plies are aligned, the bolt should be inserted with the exception of the drift-pin locations if used, and the plies should be capable of being drawn together freely until they are firmly in contact. If this is the case the drift-pins may be removed and replaced by bolts. With the plies drawn together and all the bolts inserted, the next step is to tighten the bolts to the condition known as snug tight. There is no commonly accepted definition of snug tight for preloaded bolts but the condition is well understood by steel erectors. This may be done easily by the shear wrench for TCBs but preloaded bolts only need to be hand tightened using podger spanners to be snug tight.

Once all the bolts are snug tight, the preloading of the TCBs can commence using the shear wrench, until the spline shears off as described in Section 5. When the joint has been assembled and all the bolts are snug tight, it is advisable to preload the bolts as soon as possible thereafter, bearing in mind several factors, temporary stability, lining and levelling of the structure, or access and propping etc. It is considered best to preload the bolts in a staggered pattern and where there are more than four bolts in a joint, they should be preloaded from the centre of the joint outwards i.e. outwards from the most rigid part of the joint.

However, it may not be possible to draw the plies together freely until they are firmly in contact. This may be due to many reasons; rolling tolerances, (i.e. misaligned webs or overall depth of profile) ply or profile distortion due to rolling or welding (curved flanges) or the plies may be bolted or welded in position. In these circumstances it is common to replace the drift-pins with fit-up or sacrificial bolts, which are completely tightened for the sole purpose of drawing the plies firmly together. This then allows the insertion and snug tightening of the remaining bolts and the replacing of the sacrificial bolts by TCBs, Grade S10T. The sacrificial bolts are discarded when removed. The preloading of all the bolts can then commence in the normal way. The use of multiple thin cover plates instead of one thick cover may offer advantages since it is easer to draw together freely many thin plies than fewer thick ones. The use of full-face shims to overcome the difficulties that arise from distortion and rolling tolerances should also be considered; see Worked Example 1.

When drifting of holes or sacrificial bolts cannot bring all the plies together the option of reaming and inserting larger diameter bolts should be considered and new structural calculations performed to prove the adequacy of the joint with larger bolts inserted. Some designers set out the bolt spacing in a potentially difficult joint for the next bolt size above the one used in the connection in order to cover the eventuality that reaming and bolt replacing may be required. The trial assembly of potentially difficult joints during the design phase prior to fabrication should be considered.

The distortion of welded end plates in curving or dishing towards the welded side of the end plate often results in no contact at the tips of the plies. Prying action, if taken into account in the design, relies upon contact at or near the tips of the plies. If contact at the tips is not present the end plate must be sized on the assumption of single curvature bending. In this and other circumstances tapered shims may be inserted into the gaps to provide contact when the design assumes prying.

Careful consideration at the design and detailing stages should alleviate most joint assembly problems. In fact, joint assembly on a project utilizing preloaded bolted connections should be thought of as part of the much larger planning stage at the beginning of a project where erection sequence, temporary stability, access, propping and safety etc should be considered. The special lightweight electrical powered shear wrench used to preload TCBs is of great advantage in these overall considerations.

6.5.4 Storage and handling

A TCB Grade S10T, like all high-strength bolts, is a precision made engineering product and hence should be stored and handled with care at all stages up to and including preloading. Any high-strength bolt cannot be tightened properly if the threads have been damaged. Moreover, a high-strength bolt should never receive any additional processing after it has been dispatched from the manufacturer i.e. it should not suffer cold or hot bending, welding, heat treatment, surface treatment etc. This prohibition includes a ban on the additional application of any lubricant in addition to that applied to the TCB bolt, nut or washer by the manufacturer.

On site, it is prudent to store TCBs, like any other high-strength bolt, under cover in their supplied containers away from dirt, mud, rain or snow. The controlled preloading of high-strength bolts with mud or dirt attached to the threads or with rusty threads cannot be guaranteed. Tension Control Bolts Ltd supply self-colour bolts although most are delivered in a coated condition including Greenkote™, described in Section 3.7, galvanizing and electro-galvanizing.

If required, TCBs may be supplied as complete sets, which aids the safe handling of the bolts on site rather than having the bolts, nuts and washers all in separate containers/boxes. However, this may not be practical when erecting large plate girder or box girder structures because an erector cannot access both sides of the joint at the same time. In such cases the parts of the bolt set must be delivered separately to the erection point: The bolts to one side of the joint and the nuts and washers to the other side.

7 PROCUREMENT

7.1 Quality assurance

CTICM's report recommended that a minimum of five installation or preload tests by assembly lot* should be required at the time of ordering TCBs, Grade S10T, see Sections 3.7 and 6.5.4. JSS II – 09:1996, Table 9 also recommends five preload tests. This means preloading a TCB, with the shear wrench (Appendix B) in a load cell which allows the axial tension induced in the bolt by the preloading to be recorded when the spline shears off. In order to justify the use of the Specified Minimum Preloads in Table 3.1 and the Preloading Forces in Table 3.2, it is recommended that the results of the five tests should be required to meet the following criteria on the minimum individual, on the minimum mean and maximum standard deviation values. It is recommended that, while the standard deviation criterion should always be met, lower mean and individual values may be accepted on the condition that an adequate reduction in the design preload value is adopted for slip resistance connection. No reduction in the bolt design preload for direction tension alone would be required in the latter case.

Table 7.1 *Test requirements for TCB Grade S10T*

Bolt	M12	M16	M20	M22	M24	M27	M30
Min. individual value kN	64	119	185	229	267	346.5	424
Min. Mean value kN*	67.1	124.3	193.6	239.8	279.4	363.0	444.4
Max. Stand. deviation kN**	4.05	8.34	12.75	15.69	18.63	24.38	29.8
Design value kN	61	113	176	218	254	330	404

* Taken as $\bar{x}$

** Taken as s_{n-1}

where $$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad \text{and} \quad s_{n-1} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

and n is the number of tests which should be at least 5.

7.2 Impact strength

An impact strength requirement for TCBs, Grade S10T, is optional in the two Japanese standards referred to in Section 4.1. Consequently, when it is planned to use TCBs, Grade S10T, in fatigue or seismic and/or at very low service temperatures it is advised that a specific impact strength test be agreed between customer and manufacturer at the time of order.

* Assembly lot is not defined in the CTICM report but could reasonably be taken to be a single batch from the supplier of a particular bolt size and length, and with a particular surface coating.

8 REFERENCES

1. BS 5950 Structural use of steelwork in building
   BS 5950-1:2000-1: Code of practice for design. Rolled and welded sections
   BS 5950-2:2001-2: Specification for materials, fabrication and erections. Rolled and welded sections
   British Standards Institution
2. BS 4395 Specification for high strength friction grip bolts and associated nuts and washers for structural engineering
   BS 4395-1:1969 Part 1 General grade
   BS 4395-2:1969 Part 2 Higher grade (parallel shank)
   British Standards Institution
3. BS 4604 Specification for use of high strength friction grip bolts in structural engineering – Metric series
   BS 4604-1:1970 General grade
   BS 4604-2:1970 Higher grade (parallel shank)
   British Standards Institution
4. National Structural Steelwork Specification for Building Construction Fourth Edition
   The British Constructional Steelwork Association Limited &
   The Steel Construction Institute, 2002
5. BS 5400 Steel, concrete and composite bridges.
   BS 5400-3:2000 Steel, concrete and composite bridges. Code of practice for design of steel bridges
   British Standards Institution, 2000
6. Evaluation of the High Strength Bolt for preload (product type TCB) and its use in France (Ref. CTICM No 2001 – 07)
   CTICM (Centre Technique Industriel de la Construction Métallique), France, 2001
7. prEN 114399 High-strength structural bolting assemblies for preloading.
   A series of CEN/TC185-WG6 committee documents, which will be published as parts of EN 114399, from 2005 onwards.
8. EN 11993-1-8 Eurocode 3. Design of steel structures: Design of joints
   (to be published in 2004)
9. JIS B 1186 - 1995
   Sets of high strength hexagon bolt, hexagon nut and plain washers for friction grip joints
   Japanese Standards Association
10. Joints in steel construction: Moment connections (P207)
    The Steel Construction Institute and The British Constructional Steelwork Association Limited, 1995
11. JSS II-09-1996
    Sets of Torshear Type High Strength Bolt, Hexagon Nut and Plain Washer for Structural Joints.
    Society of Steel Construction of Japan

12. Technical Note TN 98
Design guidance notes for friction grip bolted connections.
B. D. Cheal
Ciria, 1980

13. Structural Steelwork Connections
G. W. Owens and B. D. Cheal
Butterworths

14. Torque-Tension Characteristics of T.C.Bolts
R. G. Slutter
Fritz Engineering Laboratory
Lehigh University

15. Joints in steel construction: Simple connections (P212)
Edited by A. S. Malik
The Steel Construction Institute and The British Constructional Steelwork Association Limited, 2002

16. Iles, D. C.
Design guide for composite highway bridges (P290)
The Steel Construction Institute, 2001

17. Advisory Note: AD243 Splices within unrestrained lengths
New Steel Construction, vol. 8(6), 11/00

18. Advisory Note: AD244 Second order moments
New Steel Construction, vol. 8(6), 11/00

19. Advisory Note: AD086 Lack of fit in HSFG bolted joints (Amended)
Steel Construction Today, vol. 5(4), 07/91

APPENDIX A WORKED EXAMPLES

Example **Page**

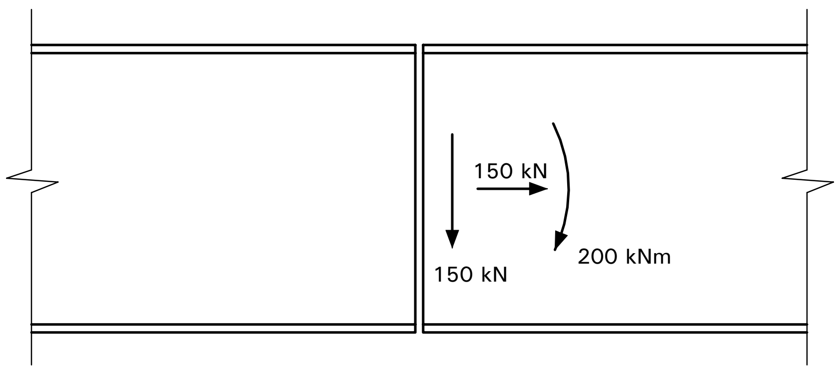
Note: All references in the margin are to BS 5950-1:2000 unless otherwise stated.

EXAMPLE 1: BEAM SPLICE, DESIGNED FOR NON-SLIP IN SERVICE

This example is based on the Bolted Splice – Worked Example in Section 5.4 of *Joints in steel construction – Moment Connections* (P207)[10].

Design a bolted cover plate splice for a 457 × 191 × 67 UB S275 with shot blasted faying surfaces (Class A faying surface, see Table 35, BS 5950-1:2000).

The connection is to carry the bending moment, shear force and axial tension shown (at ultimate limit state). 6.4.1



D_B = 453.4mm, B_b = 189.9mm, t_b = 8.5 mm, T_b = 12.7 mm

T = 12.7 < 16 mm ⇒ p_y = 275 N/mm^2 (Table 9 – BS 5950-1:2000)

General Notes

It is generally the case that joint rotation within a beam splice, as a result of bolt slip, is both visually and functionally unacceptable in service. Rotation at the splice may also invalidate the frame analysis where continuity has been assumed. It is therefore recommended that preloaded bolts such as TCBs be used in bolted cover plate splices.

In this example, it is assumed that the splice is located close to a point of inflexion in the buckled shape of a laterally unrestrained beam or the beam is laterally restrained. If these conditions were not satisfied, reference would be made to Clause 6.1.8.4 BS 5950-1:2000 and Annexes C.3, B.3 and I.5, as appropriate, to determine the additional moments and amplification required. Advisory notes, AD 243[17] and AD 244[18] deal with these topics.

Beam splices in building structures are often designed assuming that the flanges alone resist the bending moment and axial force. An example of a deep plate girder splice, designed with the web cover plates sharing in the transfer of moment, can be found in *Structural Steelwork Connections* by Owens & Cheal[12].

Distribution of internal forces

Calculate the larger force, F_t, in the beam tension flange, or the beam compression flange

In tension:

$$T = \frac{M}{(D_b - T_b)} - \frac{N}{2} = \frac{200 \times 10^3}{(453.4 - 12.7)} - \frac{(-150)}{2} = 529 \text{ kN}$$

In compression:

$$C = \frac{M}{(D_b - T_b)} + \frac{N}{2} = \frac{200 \times 10^3}{(453.4 - 12.7)} + \frac{(-150)}{2} = 379 \text{ kN}$$

Flange capacity and design of flange cover plates

Assume that pairs of M20 TCB bolts in 22 mm holes will connect the cover plates.

$$A_{ef} \geq \frac{F_t}{p_{yf}}$$ 3.4.3

A_{ef} = The effective flange area

= 1.2 × net area (S275), but ≤ gross area

= 1.2 × (189.9 – (2 × 22) × 12.7) but ≤ 189.9 × 12.7

= 2224 mm² but ≤ 2412 mm²

And $\frac{F_t}{p_y} = \frac{529 \times 10^3}{275} = 1924 \text{ mm}^2 < 2224 \text{ mm}^2$ Flange capacity OK

Plates

Try a single, external cover plate, 180 mm wide not more than 16 mm thick, grade S275, $p_y = 275$ N/mm². Design the plates for the (larger) tension force. As noted above, assume M20 TCB in 22 mm holes.

By inspection, A_{ep} will govern – effective area of cover plate rather than gross area of cover plate.

It is required that $A_{ep} > \frac{F_t}{p_{yp}}$

$$1.2 \times t_p \times (180 - (2 \times 22)) \geq \frac{529 \times 10^3}{275}$$

Giving $t_p \geq \dfrac{529 \times 10^3}{275 \times 1.2 \times (180 - (2 \times 22))}$

$= 11.8$ mm, say 12 mm

Use 180 × 12 cover plate – S275

Design of flange bolts against slip in service — 6.4.1

For M20 preloaded TCBs in standard clearance holes,

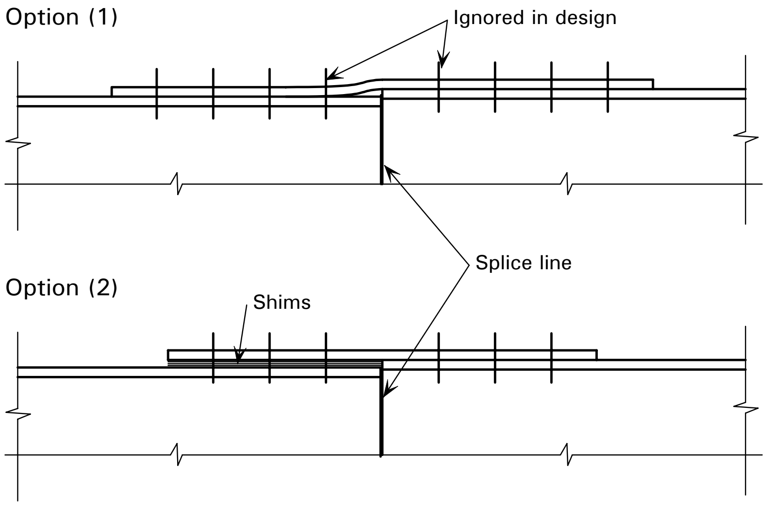
$P_o = 176$ kN (see Table 3.1), $k_s = 1.0$, $\mu = 0.5$

$P_{sL} = 1.1\, k_s\, \mu\, p_o = 1.1 \times 1.0 \times 0.5 \times 176 = 96.8$ kN — 6.4.2

(Alternatively, use Table C3 - Appendix C, Table for 'Class A' faying surface)

No. of bolts required $\dfrac{529}{96.8} = 5.46$. Therefore, use 6 bolts (3 pairs) each side

Warning – Allowance for rolling margins — 6.1.2



Often at beam splices, the overall depth of the two beam sections do not equal each other, owing to rolling margins.

Two options are possible to cater for this: (1) ignore the contribution of the bolt rows nearest the splice line or (2) the use of shims. In this worked example, it is assumed that the overall depths of the beam sections are equal. However, in practice the design engineer must decide if this assumption is realistic. Reference should be made to Advisory Note AD086[19] for further guidance concerning lack of fit in preloaded bolted joints.

Design of flange bolts after slipping 6.4.4

Shear – No packing (Clause 6.3.2.2) has been used. T_g (Grip Length) does not exceed $5d$ (Clause 6.3.2.3). L_g (Lap Length) does not exceed 500 mm (Clause 6.3.2.5).

Therefore, $P_s = p_s A_s$ 6.3.2.1

p_s = 400 N/mm^2 (10.9) Table 30, BS 5950-1:2000

A_s = 245 mm^2 (M20) Table 4.3

$\Rightarrow \quad P_s = \dfrac{400 \times 245}{10^3} = 98\text{ kN} > P_{sL} = 96.8\text{ kN}$ OK.

Bearing $P_{bg} = 1.5\, d\, t_p\, p_{bs}$ and d = 20 mm

t_p = 12 mm $< T$ = 12.7 mm

$P_{bg} \le 0.5\, e\, t_p\, p_{bs}$ and e = 60 mm

p_{bs} = 460 N/mm^2

(Table 32 BS 5950-1:2000)

$$P_{bg} = \frac{1.5 \times 20 \times 12 \times 460}{10^3}$$

$= 165.6\text{ kN} > P_{sL} = 96.8\text{ kN}$ OK

$$\text{Or } P_{bg} = \frac{0.5 \times 60 \times 12 \times 460}{10^3}$$

$= 165.6\text{ kN} > P_{sL} = 96.8\text{ kN}$ OK

∴ Cover plate detail acceptable

Cover plates and bolts are adequate. The compression flange forces are lower but an identical detail is chosen for consistency and to avoid potential errors.

Web plates and bolts

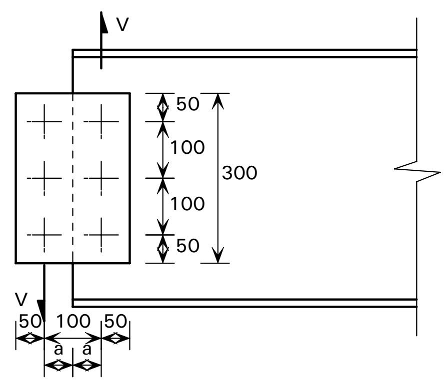
Try the following:

2 No 10 mm web plates

M20 preloaded TCBs in 22 mm holes

a = 50 mm

p = 100 mm (pitch)



Note:
Minimum bolt spacing and end and edge distances complied with.

Web plates 6.2.1

In shear, it is required that:

$V < P_v$ 4.2.3

$P_v = 0.6 \times A_{v.net} \times p_{yp}$ (conservative)

$= 0.6 \times 0.9\,(L - n_r \times d_o) \times t_p \times p_{yp} \times n_p$

$= 0.6 \times 0.9 \times (300 - 3 \times 22) \times 10 \times 275 \times 2 \times 10^{-3}$

$= 695$ kN > 150 kN (Low Shear) OK 4.2.5.4

In bending (due to shear)

$M \leq M_c$

$M = V \times a = 150 \times 0.05 = 7.5$ kNm

$$I_p = \frac{10 \times 300^3}{12} - \frac{3 \times 10 \times 22^3}{12} - (2 \times 10 \times 22 \times 100^2)$$

$= 18.1 \times 10^6$ mm^4

$M_c = p_{yp} \times Z_{Net}$ (conservative)

$$= 275 \times 10^{-3}\ \frac{2 \times 18.1 \times 10^6}{150 \times 10^3} = 66.4 \text{ kNm} > 7.5 \text{ kNm} \quad \text{OK}$$

Web plate bolts

It is required that:

$F_r \leq P_s$

F_r = Resultant bolt load $= \sqrt{F_m^{\,2} + F_v^{\,2}}$

$$Z_b = \frac{n_b(n_b + 1)p}{6} = \frac{3 \times 4 \times 100}{6} = 200 \text{ (see P207 for equation)}$$

$$F_m = \frac{150 \times 50}{200} \quad \left(\frac{V \times a}{Z_b}\right) = 37.5 \text{ kN}$$

$$F_v \quad \frac{V}{n_b} = \frac{150}{3} = 50 \text{ kN}$$

Therefore, $F_r = \sqrt{(37.5)^2 + (50)^2} = 62.5$ kN

P_s = The lesser of the slip resistance of the bolt; and after slipping, the shear resistance of the bolt, the bearing capacity of the bolt in the cover plates(s), or the bearing capacity of the bolt in the beam web. 6.4.4

Slip resistance $= 2 \times 96.8 = 193.6$ kN > 62.5 kN

Shear resistance (after slipping) $= 2 \times 98.0 = 196.0$ kN > 62.5 kN

Bearing capacity after slipping 6.4.4

$P_{bg} = 1.5\, d\, t_p\, p_{bs}$

Cover plates $= 2 \times 1.5 \times 20.0 \times 10.0 \times 460 \times 10^{-3}$

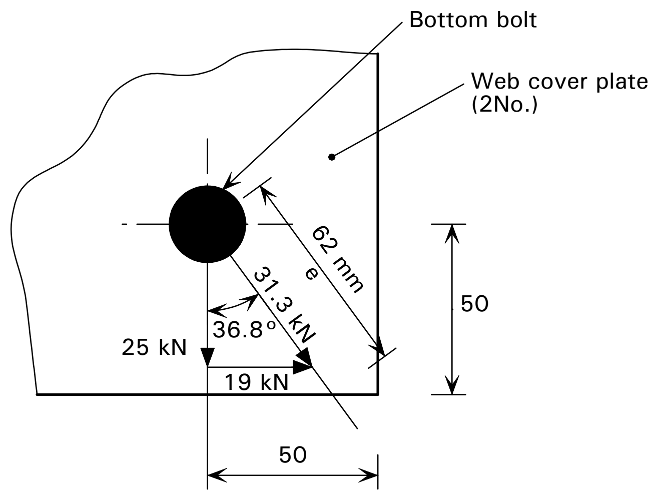
$= 276$ kN > 62.5 kN OK

Beam web $= 1.5 \times 20.0 \times 8.5 \times 460 \times 10^{-3}$

$= 117$ kN > 62.5 kN OK

Note: Although the bearing load (62.5 kN) in the beam web and cover plates is low, the edge distances are smaller than $3d$. The end distances e in the direction of the resultant bolt loads should therefore be checked for completeness. One could, in this case, conservatively take e as 50 mm but the following checks evaluate e for the direction of the bolt load.

Cover Plate

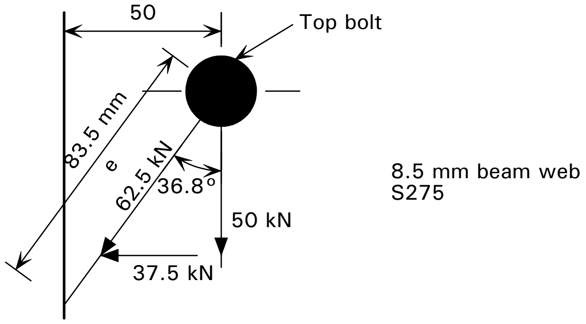


$$e = \frac{50}{\cos\theta} = \frac{50}{\cos 36.8} = 62 \text{ mm} > 3d \text{ OK}$$

$\Rightarrow P_{bg} = 0.5e\, t_p\, p_{bs}$ 6.4.4

$$= \frac{0.5 \times 62 \times 10 \times 460}{10^3} = 142.6 \text{ kN} > 31.3 \text{ kN} \quad (62.5 \text{ kN} / 2)$$

Beam web

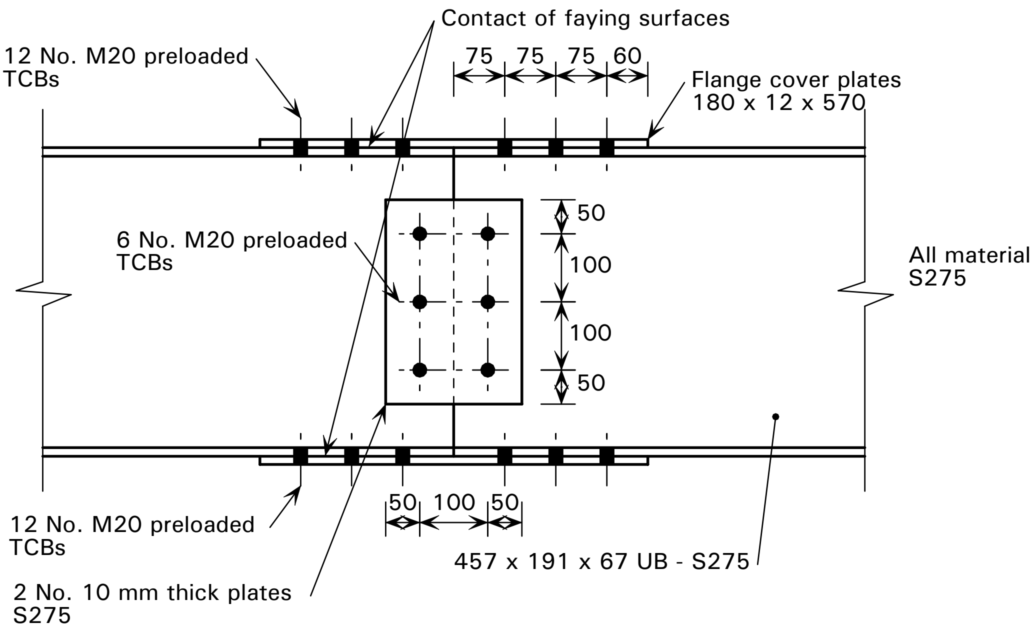


$$e = \frac{50}{\sin\theta} = 83.5 \text{ mm} > 3\text{d}$$

$$P_{bg} = \frac{0.5 \times 83.5 \times 8.5 \times 460}{10^3} = 163 \text{ kN} > 62.5 \text{ kN}$$

Detail adequate

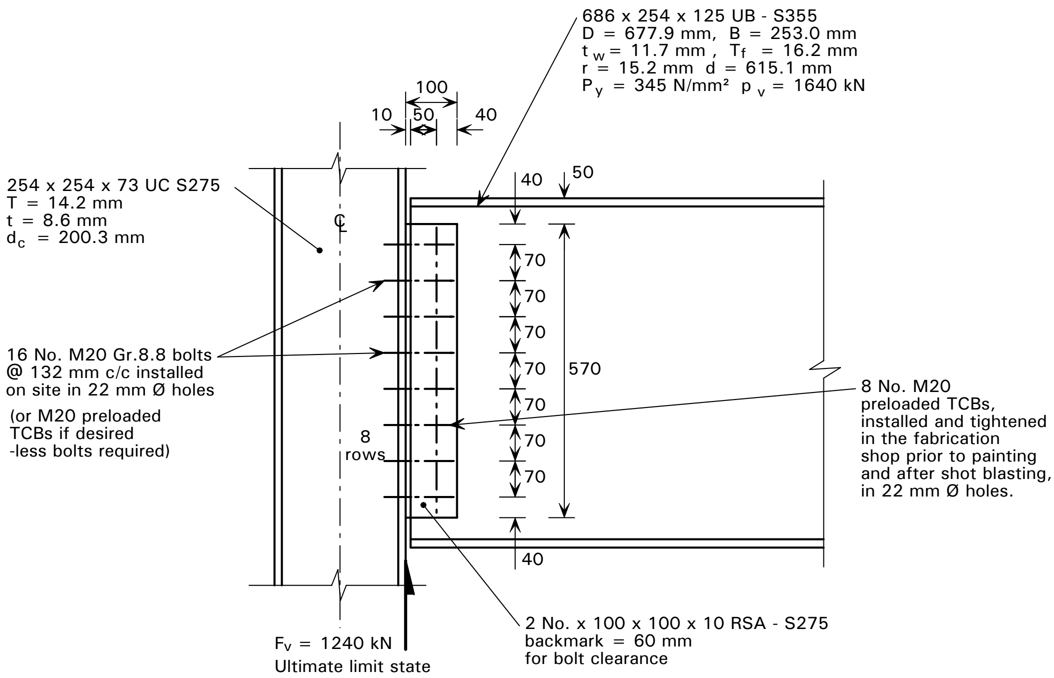
Splice Detail



The Steel Construction Institute Silwood Park, Ascot, Berks SL5 7QN Telephone: (01344) 623345 Fax: (01344) 622944 **CALCULATION SHEET**	Job No. CDA 134	Sheet 1 of 5	Rev
	Job Title TC Bolts		
	Subject Example 2 – Double Angle Web Cleats		
	Client TCB Ltd	Made by TCC	Date Jun 2004
		Checked by AW	Date Jul 2004

EXAMPLE 2: DOUBLE ANGLE WEB CLEAT IN SIMPLE CONSTRUCTION

Check the connection below for its adequacy to carry a shear of 2400 kN (Option b, Non-slip in service) 6.4.1



General notes

Reference should be made to P212 *Joints in steel construction – Simple connections*[15] for a full treatment of double angle web cleats (DAC) connections. This example highlights only the major features of the connection and emphasises those aspects pertaining to preloaded TC bolts. This connection detail satisfies the basic requirements of ductility and rotational stiffness for a pin/shear connection in simple construction. The cleats are positioned as close to the top flange of the beam as possible and the depth of the angle cleat at 570 mm is greater than 0.6 D_b = 407 mm, thereby providing adequate positional and torsional restraint to the beam.

The standard DAC connection (M20 GR 8.8 bolts plus 90 × 90 × 10 RSA-S275 Cleats) for a 686 × 254 × 125 UB-S355 will only provide a vertical shear resistance of 930 kN plus a high (766 kN) horizontal tying resistance. The limiting factor for such connections is usually the bearing capacity of the web of the beam when the connection uses non-preloaded bolts. A vertical shear resistance of 1240 kN may be obtained by using a 10 mm – S275 flexible end plate (FEP) but this has the disadvantage of having a low (381 kN) horizontal tying resistance. Further, the FEP approach requires welding which is an additional expensive operation in the fabrication sequence. Therefore the use of preloaded TC bolts - connecting the angle cleats to the web of the supported beam, installed in the fabrication shop after shot blasting and prior to painting, offers 3 advantages:

- High vertical shear resistance
- High horizontal tying resistance (Bolted connection)
- Substitution of a high skill operation, i.e. welding, by a semi-skilled operation, bolt preloading by using an automatic non-impacting shear wrench

The beam and angle cleats should be shot blasted as part of the fabrication process. Therefore the connection assembly and bolt preloading takes place prior to painting. Hence the slip factor μ may be taken as 0.5; see Table 35, BS 5950-1:2000. If this sequence is not followed or other surface treatments are applied to the faying surfaces, the slip factor should be obtained from Table 35, BS 5950-1:2000 or determined from the results of slip tests as specified in BS 4604; see Example 7.

The 60 mm back marks and 100 × 100 × 10 RSA-S275 cleats have been chosen for simplicity and bolt clearance. In other circumstances, the standard 90 × 90 × 10 RSA-S275 cleat may be made to work and give adequate clearance for the bolts.

Loading

$F_v = 1240$ kN

Calculations

Bolt group to web of UB (Check 2 in P212) — P212, p16

Basic requirement: $F_s < 2P_s$

Resultant shear per bolt $F_s = (F_{sv}^2 + F_{sm}^2)^{1/2}$

$$F_{sv} = \frac{F_v}{n} = \frac{1240}{8} = 155 \text{ kN}$$

Moment on bolt group $M_a = F_v \times a = 1240 \times 0.06 = 74.4$ kNm

Second moment of area of bolt group

$$I_{bg} = \Sigma y^2 = 2(35^2 + 105^2 + 175^2 + 245^2) = 205{,}800$$

$$F_{sm} = \frac{M_a y_{max}}{I_{bg}} = \frac{74.4 \times 245 \times 10^6}{205{,}800 \times 10^3} = 88.6 \text{ kN}$$

$$\Rightarrow F_s = (155^2 + 88.6^2)^{1/2} = 178.6 \text{ kN}$$

(i) Slip resistance

Basic requirement $F_s \leq 2\,P_{sL}$ — 6.4.2

M20 – preloaded TCBs – $P_{sL} = 1.1\,K_s \mu P_o$ $\quad \mu = 0.5,\ P_o = 176$ kN — P_o, Table 3.1

$\Rightarrow\ P_{sL} = 1.1 \times 1.0 \times 0.5 \times 176 = 96.8$ kN $\quad (K_s = 1.0)$

and $2P_{sL} = 2 \times 96.8 = 193.6$ kN > 178.6 kN $\quad$ OK

(ii) Shear capacity after slipping

Basic requirement $F_s \leq 2\,P_s$ — 6.4.4

$$P_s = p_s A_s = \frac{400 \times 245}{10^3} = 98 \text{ kN}$$ — 6.3.2.1

No packs are used – no reduction of P_s — 6.3.2.2

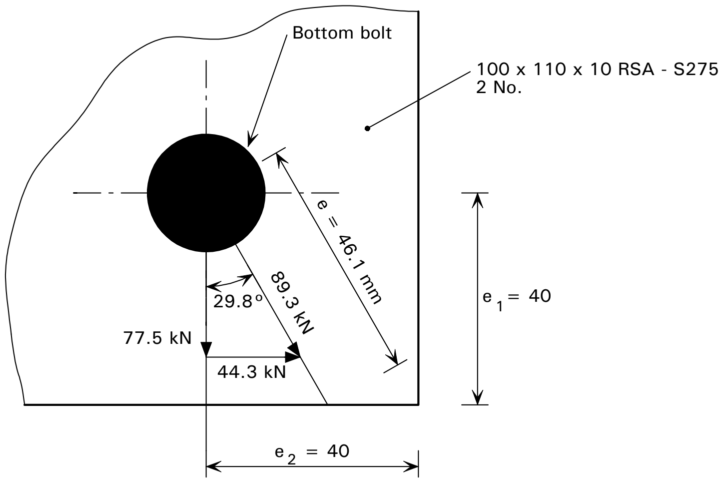
Grip length: — 6.3.2.3

$T_g = 10 + 10 + 11.7 = 31.7$ mm $< 5d = 5 \times 20 = 100$ mm – no reduction of P_s

$2P_s = 196$ kN > 178.6 kN $\quad$ OK

Bearing capacity of connecting element (after slip) (Check 3(ii) in P212) — P212, p17

Basic requirement $F_s/2 \leq P_{bg}$ — 6.4.4



$$e = \frac{40}{\cos 29.8} = 46.1 \text{ mm}$$

$$P_{bg} = 1.5 d t_p\, p_{bs} = \frac{1.5 \times 20 \times 10 \times 460}{10^3} = 138 \text{ kN}$$ — 6.4.4

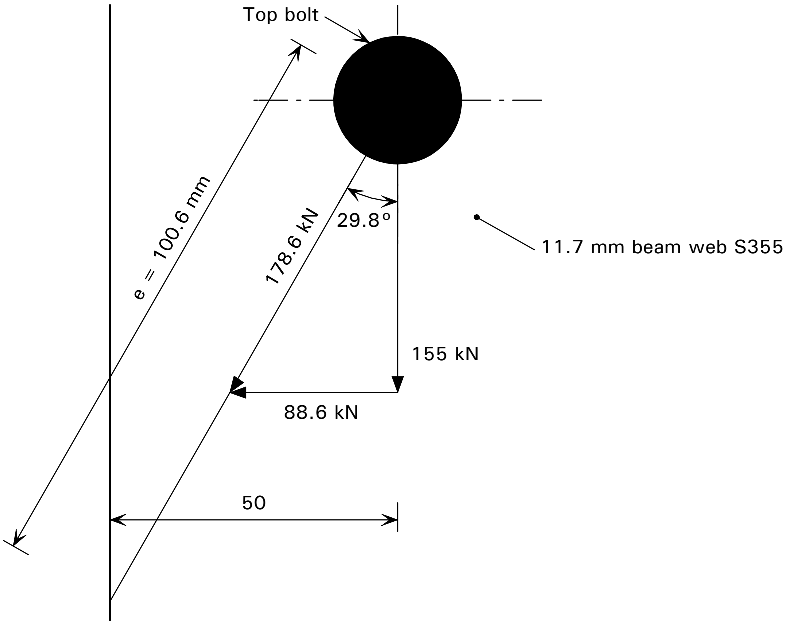
$$\text{or } P_{bg} = \frac{0.5 \times 46.1 \times 10 \times 460}{10^3} = 106 \text{ kN}$$

$\Rightarrow$ 106 kN $>$ 178.6/2 $=$ 89.3 kN $\quad$ OK

Capacity at supported beam (Check 4 in P212)

Bearing capacity (Check 4(iii)) P212, p20

Basic requirement $F_s \leq P_{bg}$ 6.4.4



$$P_{bg} = 1.5dt_p\,p_{bs} = \frac{1.5 \times 20 \times 11.7 \times 550}{10^3} = 193 \text{ kN}$$

or $$P_{bg} = 0.5et_p\,p_{bs} = \frac{0.5 \times 100.6 \times 11.7 \times 550}{10^3} = 324 \text{ kN}$$

$\Rightarrow$ 193 kN $>$ 178.6 kN OK

Shear capacity of cleats (Check 3(i)) P212, p18

Basic requirement $F_v \leq P_{v.min}$

Plane Shear

$P_v = \min(0.6p_y A_v,\ 0.7p_y K_e\, A_{v.net})$

$A_v = 0.9\ (570 \times 10) \times 2 = 10{,}260 \text{ mm}^2$

$A_{v.net} = 10260 - 16 \times 22 \times 10 = 6740 \text{ mm}^2$

and $k_c = 1.21$ (S275)

For 100 × 100 × 10 RSA – S275 - $p_y = 275 \text{ N/mm}^2$

$$\Rightarrow 0.7p_y k_c A_{v.net} = \frac{0.7 \times 275 \times 1.2 \times 6740}{10^3} = 1557 \text{ kN}$$

$\Rightarrow P_v = 1557 \text{ kN} > F_v = 1240 \text{ kN}$

The Steel Construction Institute
Silwood Park, Ascot, Berks SL5 7QN
Telephone: (01344) 623345
Fax: (01344) 622944

CALCULATION SHEET

Job No.	CDA 134		Sheet	5	of 5	Rev
Job Title	TC Bolts					
Subject	Example 2 – Double Angle Web Cleats					
Client TCB Ltd	Made by	TCC	Date	Jun 2004		
	Checked by	AW	Date	Jul 2004		

Block Shear

$P_r = 0.6 p_y t_c (L_v + K_e (L_t - kD_h))$

$L_v = e_1 + (n - 1)\ p = 40 + 490 = 530$ mm

$L_t = e_2 = 40,\quad k = 0.5$ (for single row of bolts)

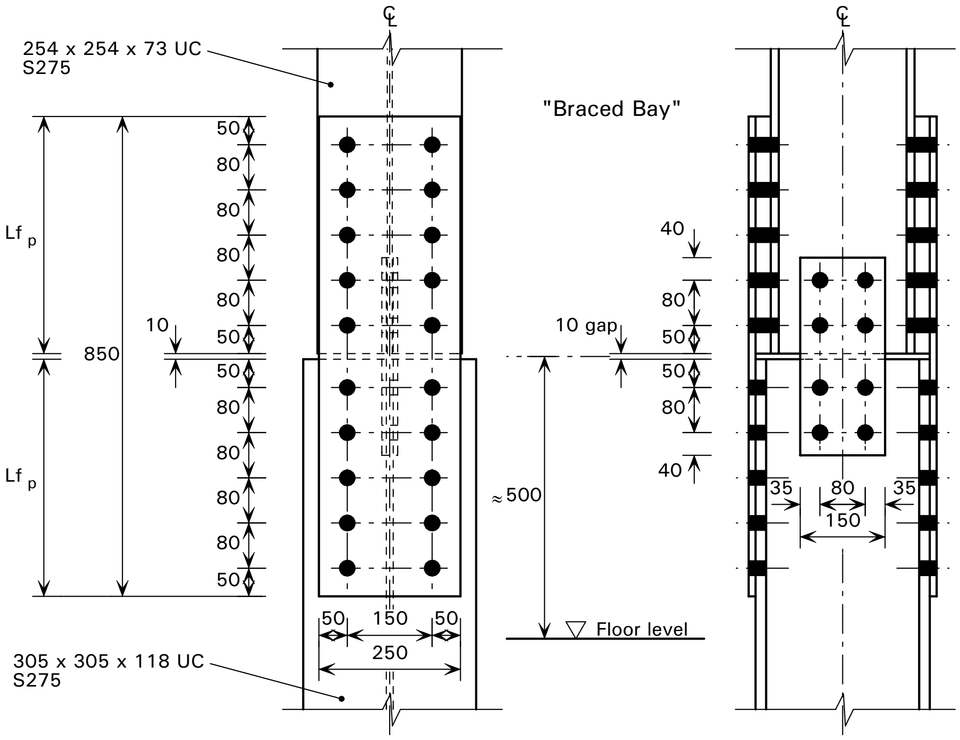
$P_r = 2\ (0.6 \times 275 \times 10\ (530 + 1.2\ (40 - 0.5 \times 22))) \times 10^{-3}$

$= 1864$ kN $> F_v = 1240$ kN OK

Detail is adequate

EXAMPLE 3: COLUMN SPLICE 6.4.1

Check the adequacy of the column splice to carry the specified loads, in accordance with BS 5950-1:2000. Design for non-slip under factored loads (special structure).



Design Information – All material S275 steel 6.4.3
M20 preloaded TCBs – Flange and Web
Faying surfaces: Class A, Table 35, BS 5950-1:2000

Flange cover plates	2/250 × 12 × 850
Flange packs	2/250 × 30 × 420
Web cover plates	2/150 × 8 × 350
Web packs	2/150 × 2 × 170

Design loading – ULS – Compression and tension

Dead	- 820 kN (DL)	Axial compression
Imposed	± 950 kN (IL)	Axial tension or compression
Moment	± 15 kNm (m)	About x-x axis of column
Shear	10 kN	Resisted by web cover plates (Negligible)
Structural integrity	420 kN	Load from floor(s) below splice

General notes

Non-preloaded bolts in clearance holes are normally used in column splices, except in cases where significant net tension is present or where slip is unacceptable. Situations where joint slip may be unacceptable include splices in a braced bay or other connections subjected to large load reversals. In these situations, preloaded bolts such as TCBs are commonly used. As a guide, net tension is considered significant when it exceeds 10% of the design strength (p_y) of the upper column.

There are two categories of bolted cover plate column splices – bearing and non-bearing. Reference should be made to Section 7 of P212, *Joints in steel construction – Simple connections*[15] for a full treatment of this subject. Obviously, when significant net tension is present, or when slip is unacceptable, cover plate column splices must be designed as non-bearing.

In simple construction, column splices are generally provided just above floor levels (500 mm approximately). Hence, moment due to strut action is considered insignificant. The moment induced in column splices placed at other positions should be checked.

In column splices joining members of different serial size, multiple packs are necessary to take up the dimensional variations. In order to limit the packing to reasonable proportions, no more than one jump in the column serial size should be taken at each splice. Design rules to allow for the effects of packing are contained in Clause 6.3.2.2, BS 5950-1:2000. As in this worked example, the effects of packing need not be checked when the connection is designed using Option C in Clause 6.4.1. However, if Option b, orthodox structures of Clause 6.4.1 had been used, then the effects of packing would have to be accounted for in checking the post slip capacity of the connection (Clause 6.4.4, BS 5950-1:2000). If the number of packs required exceeds 4, then some of them are often welded to the upper column.

Check compression and tension

254 × 254 × 73 UC – S275 (Smaller Section)

D = 254.1 mm, B = 254.6 mm, t = 8.6 mm, T = 14.2 mm, r = 12.7 mm,
d = 200.3 mm, A = 93.1 cm^2, Z_x = 898 cm^3 and p_y = 275 N/mm^2

Case I – Compression Case ($DL + IL$ + Moment)

Check for compression over whole cross-section

$$F_c = \frac{P}{A} \pm \frac{M}{Z} = \frac{(820+950)\times 10^3}{93.1\times 10^2} \pm \frac{15\times 10^6}{898\times 10^3}$$

$$= 190 \pm 16.7 = 207 \text{ N/mm}^2 \text{ max or } = 173 \text{ N/mm}^2 \text{ min } (< p_y) \text{ OK}$$

Compression over whole cross-section.

Conservatively, flange force $F \;=\; \dfrac{M}{D} + F_c\left[\dfrac{A_f}{A}\right]$ (Axial load carried by flanges).

A_f = Area of flange or cover plate attached to one flange
A = Total area of smaller column

$$\Rightarrow F_1 = \frac{15\times10^3}{254.1} + (820+950)\frac{254.6\times14.2}{93.1\times10^2} = 59\text{kN} + 687\text{ kN}$$

F_1 = 746 kN max flange force in compression.

Web Load

$$F_w = 820+950-2(820+950)\frac{254.6\times14.2}{93.1\times10^2}$$

F_w = 396 kN (plus 10 kN shear) compression

Check: (2 × 687 + 396 = 820 + 950) OK

Case II– Tension Case (*DL* + *IL* + Moment)

$$F_2 = \frac{15\times10^3}{254.1} + (950-820)\frac{254\times14.2}{93.1\times10^2} = 109\text{ kN},$$

$$f_t = \frac{109\times10^3}{254.6\times14.2} = 30.1\text{ N/mm}^2 > 0.1p_y = 27.5\text{ N/mm}^2$$

Therefore, significant net tension is present.

However, it is prudent to carry all the axial load effects on the flange alone when significant net tension is present. Thus there is no axial web load for case II.

Maximum axial tensile load per flange

$$F_2 = \frac{950-820}{2} + \frac{15\times10^3}{254.1} = 124\text{ kN tension}$$

As significant net tension is present and assuming that slip is unacceptable, design the column splice as non-bearing using preloaded TCBs. In addition design for non-slip under factored loads (option c in Clause 6.4.1). It should be noted that option b, Clause 6.4.1, BS 5950-1 2000 may also be used at the discretion of the designer. 6.4.1

Case III *DL* (Alone) + Moment

Note: It is prudent to check for all of the axial load effects on the flanges. Therefore there is no axial web load for case III.

$$F_3 = 820\times\frac{254.6\times14.2}{93.1\times10^2} \pm \frac{15\times10^3}{254.1}$$

F_3 = 318kN ± 59kN

Minimum = 259 kN Compression.

Maximum = 377 kN Compression.

Therefore, no net tension for case III (and F_1 = 746 kN > F_3 = 377 kN) OK

Structural Integrity

Tension Load per Flange = $\dfrac{420\,\text{kN}}{2}$ = 210 kN

Flange cover plate

Axial capacity of flange cover plates

Basic requirement for compression $F_1 \leq p_y A_{fp}$

F_1 = 746 kN compression

Compression capacity = $p_y A_{fp}$ - Area of flange or cover plate attached to one flange

$\dfrac{275 \times 250 \times 12}{10^3}$ = 825 kN

And F_1 = 746 kN ≤ 825 kN OK

Basic Requirement For Tension

$F_2 \leq \min (p_y A_{fp}$ or $k_e p_y A_{fp.net})$

k_e = 1.2 (S275) 3.4.3

$A_g = 250 \times 12 = 3000$ mm²

$A_{net} = 250 \times 12 - 2 \times 22 \times 12 = 2472$ mm²

$A_{eff} = k_e A_{net} = 1.2 \times 2472 = 2966$ mm² < 3000 mm²

Tension capacity = $\dfrac{275 \times 2966}{10^3}$ = 816 kN

and F_2 = 124 kN < 816 kN OK

M20 TCBs P_{sL} = 79.2 kN Table C.5, Class A faying surfaces

⇒ Capacity = 10 × 79.2 = 792 kN > F_1 = 746 kN > F_2 = 124 kN OK

Web cover plates

F_w = 396 kN – compression, Case 1

Basic Requirement. $F_w \leq p_y A_{wp}$

Compression capacity $= \dfrac{275 \times 2 \times 150 \times 8}{10^3}$ = 660 kN

and F_w = 396 kN < 660 kN OK

M20 TCBs P_{sL} = 158 kN (double shear) Table C.5, Class A faying surfaces

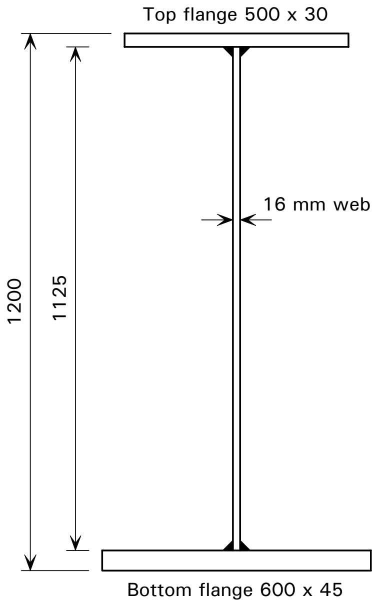
Capacity = 4 × 158 = 632 kN > F_w = 396 kN OK

Structural Integrity: by inspecting the flange cover plates and bolts will carry the tensile load per flange of 210 kN

Detail adequate

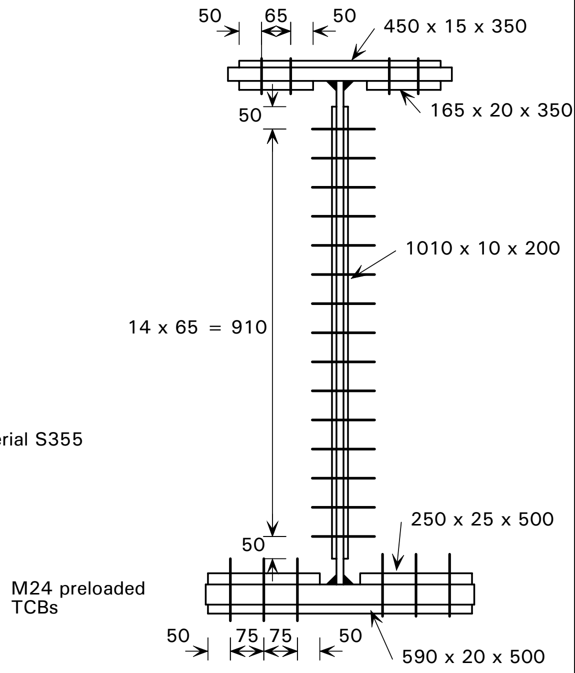
EXAMPLE 4: COMPOSITE BRIDGE GIRDER SPLICE

Redesign the composite bridge girder splice from worked example No 2 in P290: *Design Guide for Composite Highway Bridges: Worked Examples*[16], using preloaded TCBs. P290 p138-141



Girder

All material S355



Splice

Splice design

Consider main span splice (shallow end of haunch):

Shear:	ULS	= 1590 kN
	SLS	= 1310 kN
Moments		
ULS	steel only	= – 110 kNm
	composite long	= 655 kNm
	composite short	= 3370 kNm

Hence bending stresses:

	σ_b	= –91 N/mm^{-2}	Bending ± 50 N/mm^2
	σ_t	= 9 N/mm^2	Axial – 41 N/mm^2
SLS	steel only	= –95 kNm	
	composite long	= 469 kNm	

See P290

composite short = 2850 kNm

Hence bending stresses

σ_b = -75 N/mm^2 } Bending ± 41 N/mm^2

σ_t = 7 N/mm^2 } Axial – 34 N/mm^2

See P290

Capacity of preloaded bolts, Clause 3/14.5.4. Values of γ_m from Table 2(b), Part 3.

Assume M24 preloaded TCBs. Friction capacity given by:

$$P_D = k_h \frac{F_v \times \mu \times N}{\gamma_m \times \gamma_{f3}}$$

where: k_h = 1.0 as normal size holes used

F_v = 254 kN Preload (min shank tension) – see Table 3.1 (F_o -no tension)

μ = 0.50 for surfaces sprayed with aluminium,

γ_m = 1.2 (SLS) = 1.3 (ULS)

N = 2 as cover plates on both faces

γ_{f3} = 1.0

Hence P_D = 212 kN at SLS and 195 kN at ULS

If the splice were not located close to a bracing position, the design load for the compression flange would have to be increased in accordance with Clause 3/14.4.2.1.

Design to friction at SLS

Number of bolts required at bottom flange

$$= \frac{600 \times 45 \times 75 \times 10^{-3}}{212} = 10 \text{ bolts}$$

Use 3 rows of 6 bolts (As based on Worked Example 2 in P290)

Number of bolts required at top flange

$$= \frac{500 \times 30 \times 7 \times 10^{-3}}{212} = 1 \text{ bolt}$$

Use 2 rows of 4 bolts (As based on Worked Example 2 in P290)

Bolt spacing, Clause 3/14.5.1.1

SLS forces in web:

Shear = 1310 kN

Axial load = $34 \times 1125 \times 16 \times 10^{-3}$ = 612 kN

Moment = $41\ (1/6 \times 1125^2 \times 16 \times 10^{-6}) + 0.05 \times 1310$ = 204 kNm

(0.05 lever arm between centre of bolts group and centreline web splice)

Min. spacing of bolts $= 2.5 \times$ bolt diameter $= 60$ mm.

Choose 15 No. bolts @ 65 crs

Bolt group Z $= 2(65^2 + 130^2 + 195^2 + 260^2 + 325^2 + 390^2 + 455^2) \times \dfrac{1}{455}$

$= 2600$ mm

Forces on extreme web bolt due to:

Shear $=$ 1310/15 $=$ 87.3 kN

Axial $=$ 612/15 $=$ 40.8 kN

Moment $=$ 204/2.60 $=$ 78.5 kN

Resultant $= [87.3^2 + (40.8 + 78.5)^2]^{1/2} =$ 148 kN < 212 kN OK

Check at ULS

Shear capacity of bolts $= n\, A_{eq}\, \sigma_q / \gamma_m\, \gamma_{f3} \sqrt{2}$ — 3/14.5.3.5

A_{eq} conservatively taken as tensile area and $\sigma_q = 0.85 Y_b$ (0.85 × Min. yield strength)

(double shear) $= \dfrac{2 \times 353 \times 0.85 \times 900}{1.1 \times 1.1 \times \sqrt{2}} \times 10^{-3} = 316$ kN > 195kN

Bearing capacity inner ply $= k_1\, k_2\, k_3\, k_4\, \sigma_y A_{cb} / \gamma_m\, \gamma_{f3}$ — 3/14.5.3.6

Check for 16 mm web:

Capacity $= 1.0 \times 1.7 \times 1.2 \times 1.5 \times 355 \times 24 \times 16/1.05 \times 1.1$

$= 361$ kN > 195kN

Load in bottom flange

$= 600 \times 45 \times 91 = 2460$ kN Per bolt (18 bolts): 2460/18
$= 137$ kN $<$ 195kN

Load in web

Shear $= 1590$ kN

Axial $= 41 \times 1125 \times 16 \times 10^{-6} = 738$ kN

Moment $= 50 \times 1/6 \times 1125^2 \times 16 \times 10^{-6} + 0.05 \times 1590 = 248$ kNm

Forces in bolt:

Shear 106.0 kN, axial 49.2 kN, moment 95.4 kN

Resultant $= [106^2 + (49.2 + 95.4)^2]^{1/2} = 179$ kN $<$ 195 kN OK

<u>OK in bearing/shear</u>

General requirements for cover plates are given in Clause 3/14.4.1. Here the designer chose cover plates of gross sectional area approximately equal to each element (flange or web) being spliced. Note that in the bearing check on outer plies, a lower k_3 factor applies. Here the bearing is adequate by inspection.

Cover plates

Choose 10 mm for webs (bearing stress less than in web – OK) and 15, 20 and 25 mm on flanges, to roughly match and balance flange areas.

Bolt spacings

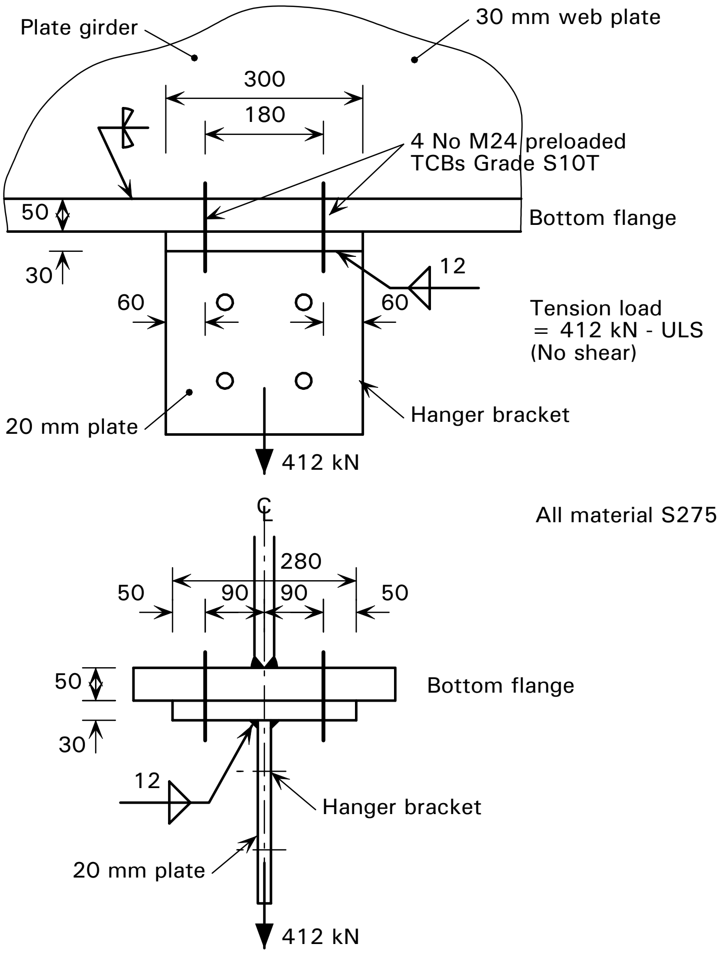
Min spacing	$= 2.5d$	$= 2.5 \times 24$	$= 60$	say 65 mm
Edge/end distance	$= 1.5d_{hole}$	$= 1.5 \times 26$	$= 39$	say 50 mm
Max. across web splice	$= 2 \times 50$	$= 100$ mm		

i.e. $< 12t$ (120 mm) OK

General Note: Owing to the high preload in the M24 TCB (254 kN) the splice does not slip into shear and bearing before ULS, unlike the original example (web bolts) in P290.

EXAMPLE 5: HANGER BRACKET

Check the adequacy of the hanger bracket shown below, in accordance with BS 5950-1 (including checks for prying action)

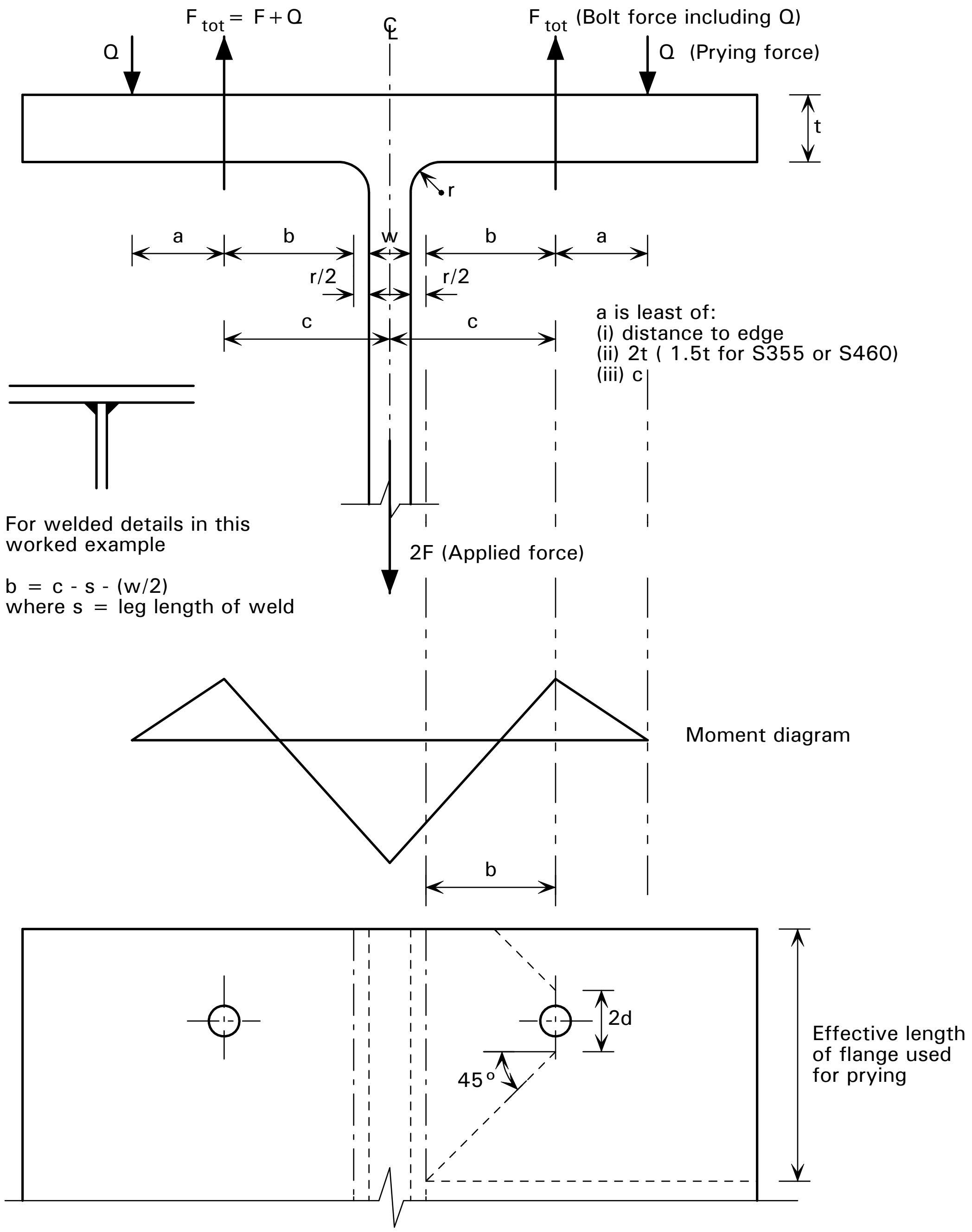


The Steel Construction Institute
Silwood Park, Ascot, Berks SL5 7QN
Telephone: (01344) 623345
Fax: (01344) 622944

CALCULATION SHEET

Job No. CDA 134		Sheet 2 of 4	Rev
Job Title TC Bolts			
Subject Example 5 – Hanger bracket			
Client TCB Ltd	Made by TCC	Date Mar 2004	
	Checked by AW	Date Apr 2004	

Prying Action - Reference: CIRIA Technical Note 98[12] Adapted From Figure 3.14



$$\textit{Prying Force } Q \quad = \quad \left[\frac{c}{2a} - \frac{1}{8}\right]F \qquad \text{(Ciria Technical Note 98)}$$

Simplified formula (there is another version which reduces Q slightly)

Calculations

$c \quad = \quad 90$ mm

$b \quad = \quad c - s - w/2 \quad = \quad 90 - 12 - \dfrac{20}{2} \quad = \quad 68.0$ mm

$a \quad = \quad B/2 - c$ or $2t$ or $c = \dfrac{280}{2} - 90$ or 2×30.0 or 90 (min.)

a $\quad = \quad 50$ or 60 or $90 \quad = \quad 50.0$ mm (min.)

Max. Effective Length of Flange per Bolt $L \quad = \quad 60 + 24 + 68 \quad = \quad 152$ mm

Use $L \quad = 150$ mm $\quad = \dfrac{300\ mm}{2}$

Prying Force Q $\quad = \left[\dfrac{c}{2a} - \dfrac{1}{8}\right] F$

Force per Bolt (Excluding prying Force) F $\quad = \dfrac{412}{4} = 103.0$ kN

Prying Force $\Rightarrow \quad Q \quad = \left[\dfrac{90}{2 \times 50} - \dfrac{1}{8}\right] \times 103 = 79.8$ kN, say 80 kN

Total Bolt force $F_{tot} \quad = F + Q \quad = 103 + 80 = 183$ kN and $F_s = 0$, No Shear

M24 preloaded TCB, $P_o \quad = 254$ kN (Table 3.1), Grade S10T

Design for non-slip under factored loads (option c in Clause 6.4.1) and $F_s = 0$ (no shear). It should be noted that option b, Clause 6.4.1, BS 5950-1:2000 may also be used at the discretion of the designer.

$\Rightarrow \quad \dfrac{F_{tot}}{0.9\ P_o} < 1.0$ 6.4.5

$= \quad \dfrac{183}{0.9 \times 254} = 0.80 < 1.0$ OK

Bolts adequate and prying accounted for. A post slip check is not required because the detail has been designed to option c) Clause 6.4.1.

Check flange of hanger

Moment at centre line of root $= F \times b - Q \times a$

$= \quad 103 \times 68 - 80 \times 50 \quad = 3004$ kN mm

Moment at centre line of bolts $= Q \times a$

$= \quad 80 \times 50 = 4000$ kN mm

$Z \quad = \dfrac{Lt^2}{6} \quad = \dfrac{150 \times 30^2}{6} \quad = 22500 \text{ mm}^3$

Stress $\quad = \dfrac{4000 \times 1000}{22500} \quad = 178 \text{ N/mm}^2$

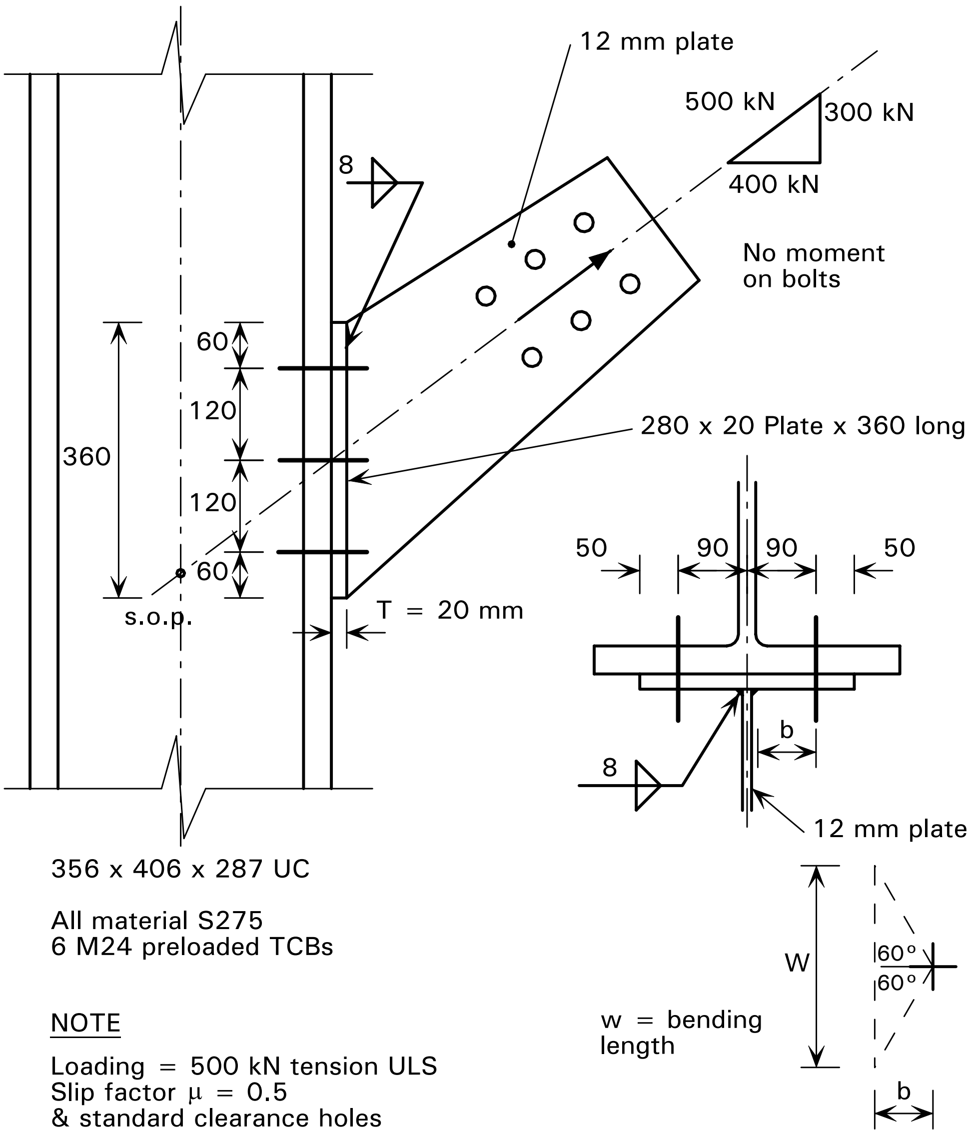
Table 9, BS 5950-1:2000. S275 material and thickness less than 40 mm
$\Rightarrow \quad p_y \quad = 265 \text{ N/mm}^2$

and $178 \text{ N/mm}^2 < 265 \text{ N/mm}^2$ OK

Detail Adequate

EXAMPLE 6: CONNECTION OF TENSILE BRACING MEMBER

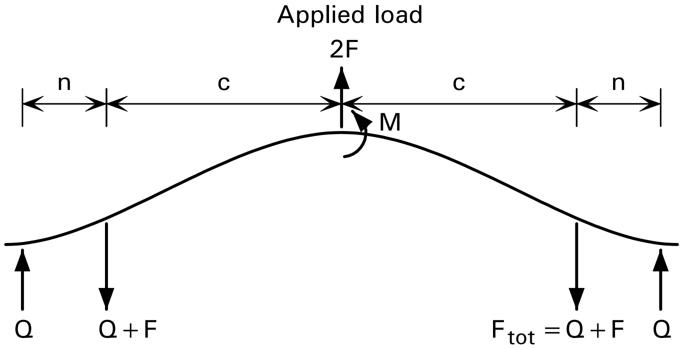
Check the attachment of a diagonal bracing member to a column, in accordance with BS 5950-1 (including consideration of prying effects). The connection is shown below.



NOTE: It is assumed that the bracing member attached to the 12 mm plate does not transfer any moment to the connection.

Prying action

The effects of prying action are determined in accordance with Owens & Cheal[13]



Flange Moment Capacity per Bolt $= \dfrac{p_y}{1.15} \times \dfrac{WT^2}{4}$ and $M = \dfrac{Fb}{2}$

Max $n \quad = 1.1T\sqrt{\dfrac{\beta P_o}{p_y}}$

(In Owens & Cheal, P_o is the symbol for the bolt proof strength)

Prying force $Q \quad = \dfrac{M}{\mathrm{n}}$

Min $Q \quad = \dfrac{b}{2n}\left[F - \dfrac{\beta\gamma P_o WT^4}{27nb^2}\right]$

(In Owens & Cheal, P_o is the symbol of the bolt proof strength)

Calculations

$b \quad = 90 - \dfrac{12}{2} - 8 \quad = 76$ mm and $\quad T \quad = 20$ mm

$p_y \quad = 265$ N/mm^2 Table 9, BS 5950-1:2000

$W \quad = 2$ Tan 60 $\times\, b \quad = 263$ mm $>$ 120 mm $\Rightarrow$ use 120 mm

For minimum thickness design – end plate

Flange Moment Capacity per Bolt $= \dfrac{p_y}{1.15} \times \dfrac{WT^2}{4}$ and $M = \dfrac{Fb}{2}$

Where force per bolt (Excluding prying force) $F \quad = \dfrac{400}{6} \quad = 66.7$ kN

$\Rightarrow \; M \quad = \dfrac{66.7 \times 76}{2} \quad = 2535$ kNmm

$\Rightarrow \quad T \quad = \quad \sqrt{\dfrac{1.15 \times 4 \times 2535 \times 10^3}{265 \times 120}} \quad = \quad 19.1$ mm

$\Rightarrow$ Use 20 mm end plate – S275 OK

Check max $n = 1.1T\sqrt{\dfrac{\beta P_o}{p_y}}$

(In Owens & Cheal, P_o is the symbol for the bolt proof strength)

β = 1 preloaded bolts

P_o = Bolt proof strength = 830 N/mm^2 Grade S10T

p_y = 265 N/mm^2

$\Rightarrow \quad n_{max} = 1.1 \times 20 \sqrt{\dfrac{1 \times 830}{265}}$

= 38.9 mm < 50 mm edge distance OK

Prying force $Q = \dfrac{M}{n} = \dfrac{2535}{38.9} = 65.2$ kN

$\Rightarrow \quad F_{TOT} = F + Q = 66.7$ kN + 65.2 kN

= 131.9 kN say 132 kN

Check minimum prying force

$$\text{Min } Q = \frac{b}{2n}\left[F - \frac{\beta \gamma P_o W T^4}{27 n b^2}\right]$$

(In Owens & Cheal, P_o is the symbol of the bolt proof strength)

β = 1 preloaded bolts

γ = 1.5 ULS design

P_o = 830 N/mm^2 but use as 0.83 kN/mm^2 , S10T proof strength

$$Q_{min} = \frac{76}{2 \times 38.9}\left[66.7 - \frac{1.0 \times 1.5 \times 0.830 \times 120 \times 20^4}{27 \times 38.9 \times 76^2}\right]$$

$\Rightarrow \quad Q_{min} = 61.3$ kN < Q = 65.2 kN OK

Check M24 preloaded TCBs, Grade S10T, P_o = 254 kN – Table 3.1 (Preload)

F_{TOT} = 132 kN and F_s = 300/6 = 50 kN

Design for non-slip in service (option b in Clause 6.4.1). It should be noted that option c, Clause 6.4.1, BS 5950-1:2000 may also be used at the discretion of the designer. 6.4.5

$P_{sL} = 1.1\, k_s\, \mu\, P_o = 1.1 \times 1.0 \times 0.5 \times 254$ 6.4.2

= 139.7 kN

$$\Rightarrow \frac{F_s}{P_{sL}} + \frac{F_{TOT}}{1.1\ P_o} \quad = \quad \frac{50}{139.7} + \frac{132}{1.1 \times 254} = \quad 0.83 < 1.0 \text{ OK}$$ 6.4.5

But F_{TOT} < $A_t\, p_t$

p_t = 700 N/mm^2 – Table 34 – BS 5950-1:2000, Grade S10T (10.9)

and A_t = 353 mm^2 Table 4.3

$$132 \text{ kN} < \frac{700 \times 353}{10^3} = 247 \text{ kN} \qquad \text{OK}$$

⇒ **Bolts adequate**

Note: A post slip capacity check is also required in accordance with Clauses 6.4.4 and 6.3.4.4 (more exact method) in BS 5950-1:2000. However, F_s = 50 kN only; and by inspection, the checks will not be critical in this case.

The Steel Construction Institute
Silwood Park, Ascot, Berks SL5 7QN
Telephone: (01344) 623345
Fax: (01344) 622944

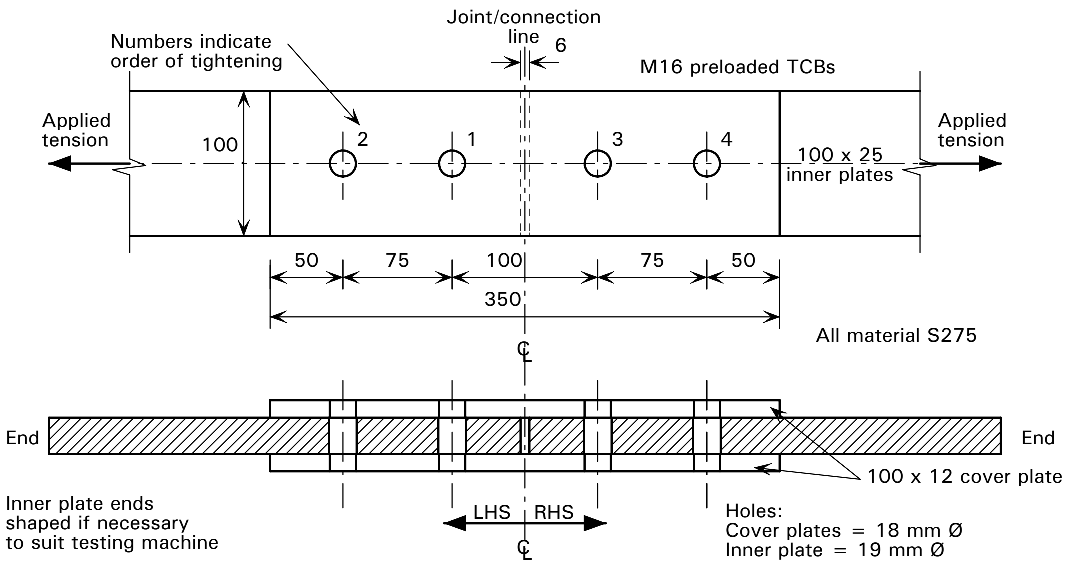
CALCULATION SHEET

Job No. CDA 134		Sheet 1 of 2		Rev
Job Title TC Bolts				
Subject Example 7 – Slip Factor				
Client TCB Ltd	Made by TCC		Date Sep 2004	
	Checked by AW		Date Sep 2004	

EXAMPLE 7: DETERMINATION OF REQUIRED SLIP FACTOR

Determine the slip factor μ for shot blasted faying surfaces for the splice connection shown below.

Test specimen



Slip load = 236 kN (lowest of 3 test values)

The test specimen is in accordance with the requirements of Appendix A – BS 4604: Part 1: 1970.

General Note

It is usually not necessary for the designer to determine the slip factor required for design from tests as one makes reference to Table 35 - BS 5950-1:2000 or Clause 14.5.4.4 in BS 5400-3:2000 for the common cases of surface treatment for faying surfaces. Values for other surface treatments are listed in alternative sources[12]. However, where it is required to determine the slip factor, at least 3 tests should be carried out in accordance with BS 4604: Part 1: 1970, and reference should be made to this standard for a full treatment of the subject.

BS 4604 states “the method of tightening the bolts in the test joints shall be the same as that in the assembly of the structure.” For preloaded TCBs this should be the standard automatic non-impacting electrical shear wrench – see Appendix B for details.

BS 4604 further states "that the slip load shall be taken as the load required to produce a displacement between adjacent points in an inner plate and a cover plate, in the direction of the applied load, in the plane of the effective interfaces of the joint of at least 0.1 mm. The slip load used for determining the slip factor should be taken as the least of the three or more test results obtained."

The standard automatic non-impacting shear wrench tightens the bolts to at least the minimum shank tension (P_o see Table 3.1) but there is always variation in the actual pre-clamping force induced in the bolts. The actual pre-clamping forces are greater than the specified minimum preloads – Table 3.1. For this reason, both sides of the test specimen will not slip simultaneously and if the test is continued beyond the first slip, two values of slip load will be obtained for each specimen. It is the first and lowest value that should be used as the slip load for the specimen/test. The two values should NOT be averaged.

Further, it is the lowest of the 3 slip loads for the 3 test specimens that should be used to determine the slip factor for the surface treatment condition of the faying surface.

The slip factor is obtained as follows:

$$\text{slip factor} = \frac{\text{slip load}}{2 \times P_o \times \text{number of bolts}}$$

- The slip load is obtained from the tests as described above
- The figure of 2 in the denominator takes account of the existence of 2 interfaces
- P_o is the specified minimum Preload (min shank tension) – see Table 3.1.
- Number of bolts – In this case the number of bolts is 2 (on one side of the joint) since each side of the joint must carry the entire load. A symmetrical arrangement is always used.

Calculations

$$\text{slip factor} = \frac{\text{slip load}}{2 \times P_o \times \text{number of bolts}}$$

slip load = 236 kN (from test)

number of bolts = 2

P_o = 113 kN - see Table 3.1.

$$\Rightarrow \text{slip factor, } \mu = \frac{236}{2 \times 113 \times 2} = 0.522$$

$\Rightarrow$ Use μ = 0.50 for design, that is, consider as a Class A faying surface, in accordance with Table 35 - BS 5950-1:2000.

APPENDIX B SHEAR WRENCHES

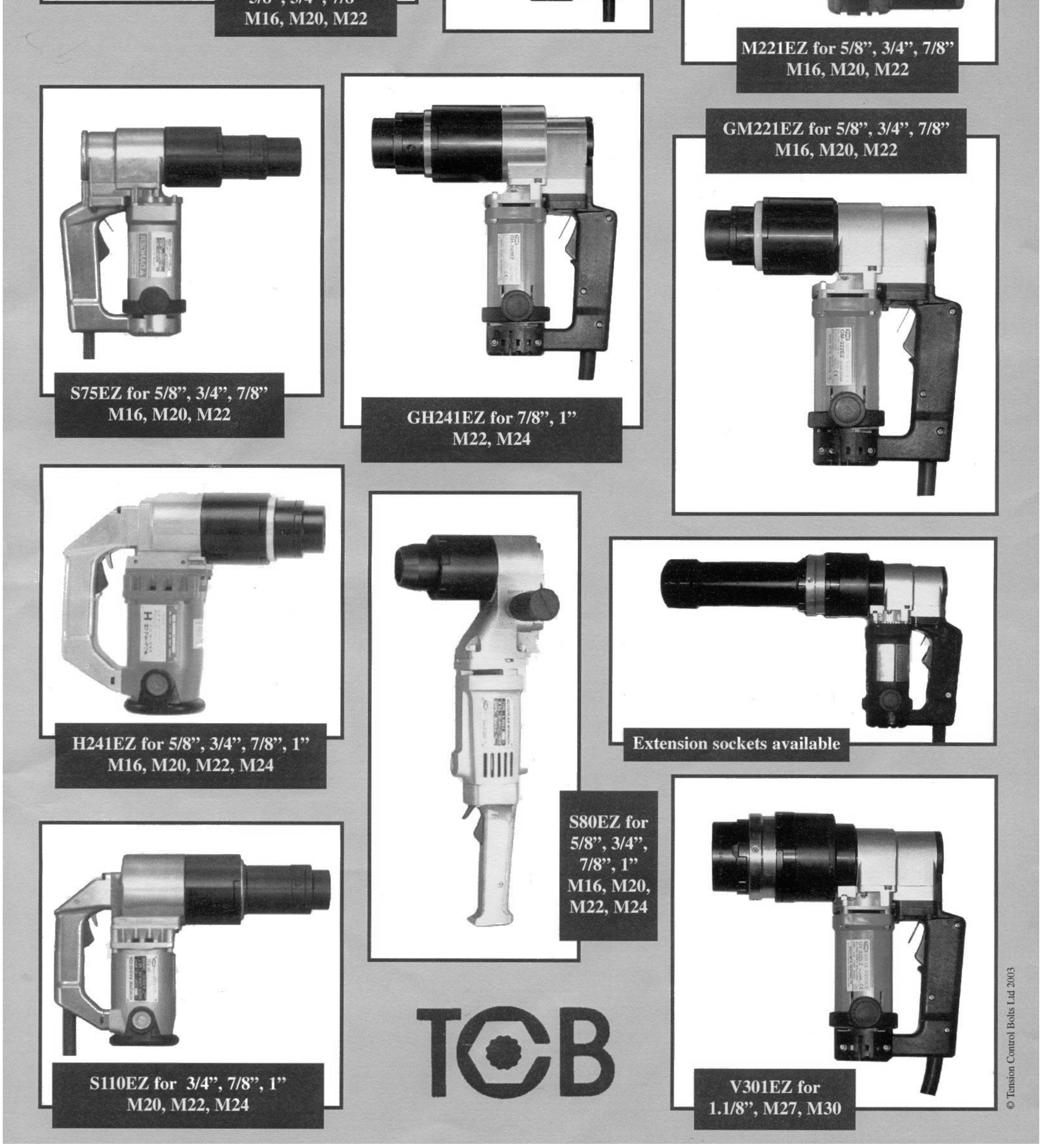
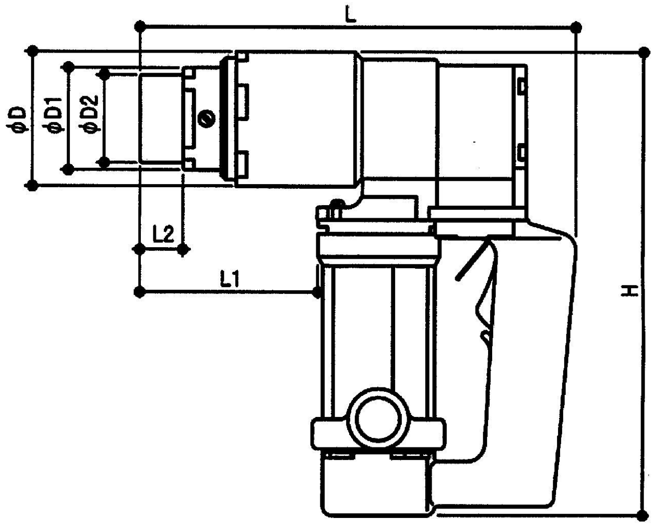
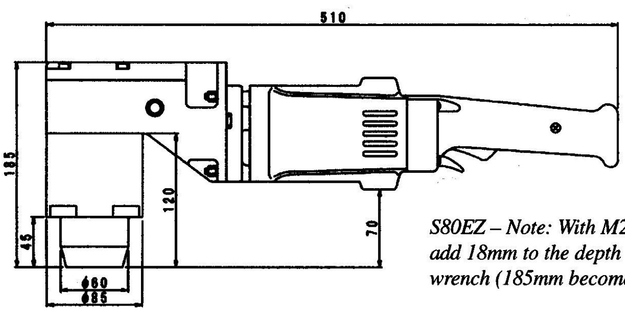


Figure B.1 *Examples of some shear wrenches*

Specifications & Dimensions

Model	GM161EZ	M221HRZ	M221EZ	S75EZ	GM221EZ	H241EZ	GH241EZ	S110EZ	V301EZ
L	222	212	244	280	244	308	263	375	272
L1	77	79	99	135	99	138	119	205	128
L2	19	24	24	39	24	24	24	25	26
D	58	75	75	68	75	85	85	100	98
D1	53	57	57	54	57	68	68	70	93
D2	39	49	49	47	49	56	56	56	75
H	251	271	241	245	259	258	274	270	271
Weight	3.8 Kg	6.0 Kg	6.0 Kg	5.5 Kg	5.0 Kg	7.8 Kg	6.2 Kg	10.3 Kg	7.2 Kg





S80EZ – Note: With M24 sockets add 18mm to the depth of the wrench (185mm becomes 203mm).

(Manual wrenches availabe upon request)

TCB Tension Control Bolts T: + 44 (0) 1948 667700 F: + 44 (0) 1948 667744
E: enquiries@tcbolts.co.uk W: www.tcbolts.co.uk

APPENDIX C DESIGN TABLES

The following design tables are presented:

Table C.1 *Design values of minimum preload of TCB Grade S10T for use in design to BS 5950 and BS 5400*

Bolt	**M12**	**M16**	**M20**	**M22**	**M24**	**M27**	**M30**
Specified Minimum Preload P_o (kN)	61.0	113	176	218	254	330	404

These values are based on stress at preload of 720 N/mm$^{2.}$. In BS 5400-3:2000, Clause 14.5.4.3 the specified minimum preload is called the Initial Load and has the notation F_o.

This table is a re-presentation of Table 3.1.

Table C.2 *Design values of minimum preload of TCB Grade S10T for use in design to Eurocode 3*

Bolt	**M12**	**M16**	**M20**	**M22**	**M24**	**M27**	**M30**
Preloading Force $F_{p,C}$ (kN)	59.0	110	171.5	212.1	247.1	321.3	393.0

These values are based upon stress at preload of 700 N/mm^2

This table is a re-presentation of Table 3.2.

Capacities of preloaded TCBs in standard clearance holes

BS 5950-1:2000
Grade S10T TCB
S275 Material
Non-slip in service

Table C.3

S10T TCBs in S275 with Class A faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.5		Bearing Capacity (kN) End distance equal to 3 x bolt diameter.										
				Single Shear	Double Shear	Single Shear	Double Shear	Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$															
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	33.6	67.1	41.4	49.7	58.0	66.2	*74.5*	*82.8*	*99.4*	*124*	*166*	*207*	*248*
16	113	124	110	62.8	126	62.2	124	**55.2**	66.2	77.3	88.3	99.4	110	*132*	*166*	*221*	*276*	*331*
20	176	194	172	98.0	196	96.8	194	**69.0**	**82.8**	**96.6**	110	124	138	166	*207*	*276*	*345*	*414*
22	218	240	212	121	242	120	240	**75.9**	**91.1**	**106**	121	137	152	182	228	*304*	*380*	*455*
24	254	279	247	141	282	140	279	**82.8**	**99.4**	**116**	**132**	149	166	199	248	*331*	*414*	*497*
27	330	363	321	184	367	182	363	**93.2**	**112**	**130**	**149**	**168**	186	224	279	*373*	*466*	*559*
30	404	444	393	224	449	222	444	**104**	**124**	**145**	**166**	**186**	**207**	248	311	414	*518*	*621*

S10T TCBs in S275 with Class B faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.4		Bearing Capacity (kN) End distance equal to 3 x bolt diameter.										
				Single Shear	Double Shear	Single Shear	Double Shear	Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$															
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	26.8	53.7	41.4	49.7	58.0	66.2	*74.5*	*82.8*	*99.4*	*124*	*166*	*207*	*248*
16	113	124	110	62.8	126	49.7	99.4	**55.2**	66.2	77.3	88.3	99.4	110	*132*	*166*	*221*	*276*	*331*
20	176	194	172	98.0	196	77.4	155	**69.0**	**82.8**	**96.6**	110	124	138	166	*207*	*276*	*345*	*414*
22	218	240	212	121	242	95.9	192	**75.9**	**91.1**	**106**	121	137	152	182	228	*304*	*380*	*455*
24	254	279	247	141	282	112	224	**82.8**	**99.4**	**116**	**132**	149	166	199	248	*331*	*414*	*497*
27	330	363	321	184	367	145	290	**93.2**	**112**	**130**	**149**	**168**	186	224	279	*373*	*466*	*559*
30	404	444	393	224	449	178	356	**104**	**124**	**145**	**166**	**186**	**207**	248	311	414	*518*	*621*

Values in **bold** are less than the single shear capacity of the bolt.

Values in *italic* are greater than the double shear capacity of the bolt.

Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies

Capacities of preloaded TCBs in standard clearance holes

BS 5950-1:2000
Grade S10T TCB
S275 Material
Non-slip in service

Table C.3 *Continued*

S10T TCBs in S275 with Class C faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.3		Bearing Capacity (kN) End distance equal to 3 x bolt diameter. Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$	Single Shear	Double Shear	Single Shear	Double Shear											
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	20.1	40.3	41.4	49.7	58.0	66.2	*74.5*	*82.8*	*99.4*	*124*	*166*	*207*	*248*
16	113	124	110	62.8	126	37.3	74.6	**55.2**	66.2	77.3	88.3	99.4	110	*132*	*166*	*221*	*276*	*331*
20	176	194	172	98.0	196	58.1	116	**69.0**	**82.8**	**96.6**	110	124	138	166	*207*	*276*	*345*	*414*
22	218	240	212	121	242	72.0	144	**75.9**	**91.1**	**106**	121	137	152	182	228	*304*	*380*	*455*
24	254	279	247	141	282	83.8	168	**82.8**	**99.4**	**116**	**132**	149	166	199	248	*331*	*414*	*497*
27	330	363	321	184	367	109	218	**93.2**	**112**	**130**	**149**	**168**	186	224	279	*373*	*466*	*559*
30	404	444	393	224	449	133	267	**104**	**124**	**145**	**166**	**186**	**207**	248	311	414	*518*	*621*

S10T TCBs in S275 with Class D faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.2		Bearing Capacity (kN) End distance equal to 3 x bolt diameter. Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$	Single Shear	Double Shear	Single Shear	Double Shear											
mm	kN	kN	kN	kN	kN	kN	KN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	13.4	26.8	41.4	49.7	58.0	66.2	*74.5*	*82.8*	*99.4*	*124*	*166*	*207*	*248*
16	113	124	110	62.8	126	24.9	49.7	**55.2**	66.2	77.3	88.3	99.4	110	*132*	*166*	*221*	*276*	*331*
20	176	194	172	98.0	196	38.7	77.4	**69.0**	**82.8**	**96.6**	110	124	138	166	*207*	*276*	*345*	*414*
22	218	240	212	121	242	48.0	95.9	**75.9**	**91.1**	**106**	121	137	152	182	228	*304*	*380*	*455*
24	254	279	247	141	282	55.9	112	**82.8**	**99.4**	**116**	**132**	149	166	199	248	*331*	*414*	*497*
27	330	363	321	184	367	72.6	145	**93.2**	**112**	**130**	**149**	**168**	186	224	279	*373*	*466*	*559*
30	404	444	393	224	449	88.9	178	**104**	**124**	**145**	**166**	**186**	**207**	248	311	414	*518*	*621*

Values in **bold** are less than the single shear capacity of the bolt.

Values in *italic* are greater than the double shear capacity of the bolt.

Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies

Capacities of preloaded TCBs in standard clearance holes

BS 5950-1:2000
Grade S10T TCB
S355 Material
Non-slip in service

Table C.4

S10T TCBs in S355 with Class A faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.5		Bearing Capacity (kN) End distance equal to 3 x bolt diameter.										
				Single Shear	Double Shear	Single Shear	Double Shear	Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$															
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	33.6	67.1	49.5	59.4	*69.3*	*79.2*	*89.1*	*99.0*	*119*	*149*	*198*	*248*	*297*
16	113	124	110	62.8	126	62.2	124	66.0	79.2	92.4	106	119	*132*	*158*	*198*	*264*	*330*	*396*
20	176	194	172	98.0	196	96.8	194	**82.5**	99.0	116	132	149	165	*198*	*248*	*330*	*413*	*495*
22	218	240	212	121	242	120	240	**90.8**	**109**	127	145	163	182	218	*272*	*363*	*454*	*545*
24	254	279	247	141	282	140	279	**99.0**	**119**	**139**	158	178	198	238	*297*	*396*	*495*	*594*
27	330	363	321	184	367	182	363	**111**	**134**	**156**	**178**	200	223	267	334	*446*	*557*	*668*
30	404	444	393	224	449	222	444	**124**	**149**	**173**	**198**	**223**	248	297	371	*495*	*619*	*743*

S10T TCBs in S355 with Class B faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.4		Bearing Capacity (kN) End distance equal to 3 x bolt diameter.										
				Single Shear	Double Shear	Single Shear	Double Shear	Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$															
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	26.8	53.7	49.5	59.4	*69.3*	*79.2*	*89.1*	*99.0*	*119*	*149*	*198*	*248*	*297*
16	113	124	110	62.8	126	49.7	99.4	66.0	79.2	92.4	106	119	*132*	*158*	*198*	*264*	*330*	*396*
20	176	194	172	98.0	196	77.4	155	**82.5**	99.0	116	132	149	165	*198*	*248*	*330*	*413*	*495*
22	218	240	212	121	242	95.9	192	**90.8**	**109**	127	145	163	182	218	*272*	*363*	*454*	*545*
24	254	279	247	141	282	112	224	**99.0**	**119**	**139**	158	178	198	238	*297*	*396*	*495*	*594*
27	330	363	321	184	367	145	290	**111**	**134**	**156**	**178**	200	223	267	334	*446*	*557*	*668*
30	404	444	393	224	449	178	356	**124**	**149**	**173**	**198**	**223**	248	297	371	*495*	*619*	*743*

Values in **bold** are less than the single shear capacity of the bolt.

Values in *italic* are greater than the double shear capacity of the bolt.

Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies

Capacities of preloaded TCBs in standard clearance holes

BS 5950-1:2000
Grade S10T TCB
S355 Material
Non-slip in service

Table C.4 *Continued*

S10T TCBs in S355 with Class C faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.3		Bearing Capacity (kN) End distance equal to 3 x bolt diameter. Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$	Single Shear	Double Shear	Single Shear	Double Shear											
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	20.1	40.3	49.5	59.4	*69.3*	*79.2*	*89.1*	*99.0*	*119*	*149*	*198*	*248*	*297*
16	113	124	110	62.8	126	37.3	74.6	66.0	79.2	92.4	106	119	*132*	*158*	*198*	*264*	*330*	*396*
20	176	194	172	98.0	196	58.1	116	**82.5**	99.0	116	132	149	165	*198*	*248*	*330*	*413*	*495*
22	218	240	212	121	242	71.9	144	**90.8**	**109**	127	145	163	182	218	*272*	*363*	*454*	*545*
24	254	279	247	141	282	83.8	168	**99.0**	**119**	**139**	158	178	198	238	*297*	*396*	*495*	*594*
27	330	363	321	184	367	109	218	**111**	**134**	**156**	**178**	200	223	267	334	*446*	*557*	*668*
30	404	444	393	224	449	133	267	**124**	**149**	**173**	**198**	**223**	248	297	371	*495*	*619*	*743*

S10T TCBs in S355 with Class D faying surfaces

Diameter of Bolt	Bolt Preload	Tension		Shear Capacity		Slip Resistance for μ = 0.2		Bearing Capacity (kN) End distance equal to 3 x bolt diameter. Thickness in mm of ply passed through.										
	P_o	$1.1P_o$	$A_t p_t$	Single Shear	Double Shear	Single Shear	Double Shear											
mm	kN	kN	kN	kN	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	67.1	59.0	33.7	67.4	13.4	26.8	49.5	59.4	*69.3*	*79.2*	*89.1*	*99.0*	*119*	*149*	*198*	*248*	*297*
16	113	124	110	62.8	126	24.9	49.7	66.0	79.2	92.4	106	119	*132*	*158*	*198*	*264*	*330*	*396*
20	176	194	172	98.0	196	38.7	77.4	**82.5**	99.0	116	132	149	165	*198*	*248*	*330*	*413*	*495*
22	218	240	212	121	242	48.0	95.9	**90.8**	**109**	127	145	163	182	218	*272*	*363*	*454*	*545*
24	254	279	247	141	282	55.9	112	**99.0**	**119**	**139**	158	178	198	238	*297*	*396*	*495*	*594*
27	330	363	321	184	367	72.6	145	**111**	**134**	**156**	**178**	200	223	267	334	*446*	*557*	*668*
30	404	444	393	224	449	88.9	178	**124**	**149**	**173**	**198**	**223**	248	297	371	*495*	*619*	*743*

Values in **bold** are less than the single shear capacity of the bolt.

Values in *italic* are greater than the double shear capacity of the bolt.

Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies.

Capacities of preloaded TCBs in standard clearance holes

BS 5950-1:2000
Grade S10T TCB
S275 & S355 material
Non-slip at ULS

Table C.5

S10T TCBs in S275 or S355 with Class A, B, C and D faying surfaces										
Diameter of Bolt	Bolt Preload	Bolt Tension Capacity	Slip Resistance for $\mu = 0.2$ "D"		Slip Resistance for $\mu = 0.3$ "C"		Slip Resistance for $\mu = 0.4$ "B"		Slip Resistance for $\mu = 0.5$ "A"	
	P_o	$0.9P_o$	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear
mm	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN
12	61.0	54.9	11.0	22.0	16.5	32.9	22.0	43.9	27.5	54.9
16	113	102	20.3	40.7	30.5	61.0	40.7	81.4	50.9	102
20	176	158	31.7	63.4	47.5	95.0	63.4	127	79.2	158
22	218	196	39.2	78.5	58.9	118	78.5	157	98.1	196
24	254	229	45.7	91.4	68.6	137	91.4	183	114	229
27	330	297	59.4	119	89.1	178	119	238	149	297
30	404	364	72.7	145	109	218	145	291	182	364

Capacities of preloaded TCBs in standard clearance holes

BS 5400- 3:2000
Grade S10T TCB
S275 Material
Non-slip at SLS

Table C.6

Diameter of Bolt	Initial Load	Slip Resistance at SLS									
		for μ = 0.25		for μ = 0.35		for μ = 0.4		for μ = 0.45		for μ = 0.5	
	F_o	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear
mm	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN
12	61.0	11.4	22.9	16.0	32.0	18.3	36.6	20.6	41.2	22.9	45.8
16	113	21.2	42.4	29.7	59.3	33.9	67.8	38.1	76.3	42.4	84.8
20	176	33.0	66.0	46.2	92.4	52.8	106	59.4	119	66.0	132
22	218	40.9	81.8	57.2	114	65.4	131	73.6	147	81.8	164
24	254	47.6	95.3	66.7	133	76.2	152	85.7	171	95.3	191
27	330	61.9	124	86.6	173	99.0	198	111	223	124	248
30	404	75.8	152	106	212	121	242	136	273	152	303

Diameter of Bolt	Initial Load	Shear Capacity At ULS		Bearing Capacity-(Post Slip) at ULS kN End distance ≥ 3 x bolt diameter. Thickness in mm of ply passed through.										
	F_o	Single Shear	Double Shear											
mm	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	37.7	75.4	50.9 (64)	61.1 (77)	*71.2 (90)*	*81.4 (103)*							
16	113	70.2	140	67.8 (85)	81.4 (103)	95.0 (120)	109 (137)	122 (154)	*136 (171)*	*163 (206)*				
20	176	110	219	84.8 (107)	102 (129)	119 (150)	136 (171)	153 (193)	170 (214)	*204 (257)*	*254 (321)*			
22	218	135	271	93.3 (118)	112 (141)	131 (165)	149 (188)	168 (212)	187 (236)	224 (283)	*280 (353)*	*359 (454)*		
24	254	158	316	102 (129)	122 (154)	142 (180)	163 (206)	183 (231)	204 (257)	244 (308)	*305 (386)*	*392 (495)*		
27	330	205	410	114 (145)	137 (174)	160 (202)	183 (231)	206 (260)	229 (289)	275 (347)	343 (434)	*441 (557)*		
30	404	251	502	127 (161)	153 (193)	178 (225)	204 (257)	229 (289)	254 (321)	305 (386)	382 (482)	490 (619)	*613 (774)*	

Notes; Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies.

A reduction for the long connection effect in accordance with Clause 14.5.5 in BS 5400-3:2000 has not been made.

Brackets indicate enclosed bearing.

Slip resistance is given by Clauses 14.5.4.2 and 14.5.4.4 as $\frac{F_v \times (0.9\mu)}{\gamma_m \gamma_{f3}}$ which, at SLS $= \frac{F_o \times 0.9 \times \mu}{1.2 \times 1.0}$ (F_t taken as $= 0$)

Shear resistance is given by Clause 14.5.3.4 as $\frac{0.85 \times \sigma_y \times A_{eq}}{\sqrt{2} \times \gamma_m \gamma_{f3}}$ which, for TCBs at ULS $= \frac{0.85 \times 900 \times A_{eq}}{\sqrt{2} \times 1.1 \times 1.1}$

Bearing resistance is given by Clause 14.5.3.6 as $A_{eb} \times \frac{k_1 k_2 k_3 k_4 \sigma_y}{\gamma_m \gamma_{f3}}$ which, at ULS =

$A_{eb} \times \frac{1.0 \times 2.5 \times [0.95 \text{ or } 1.2] \times 1.5 \times [275 \text{ or } 265]}{1.05 \times 1.1}$ (For S275 material, the yield strength is 275 N/mm^2 for thicknesses up to 16 mm and 265 N/mm^2 for thicknesses from 16 mm to 40 mm.)

Capacities of preloaded TCBs in standard clearance holes

BS 5400- 3:2000
Grade S10T TCB
S355 Material
Non-slip at SLS

Table C.7

Diameter of Bolt	Initial Load	Slip Resistance at SLS									
		for μ = 0.25		for μ = 0.35		for μ = 0.4		for μ = 0.45		for μ = 0.5	
	F_o	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear
mm	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN
12	61.0	11.4	22.9	16.0	32.0	18.3	36.6	20.6	41.2	22.9	45.8
16	113	21.2	42.4	29.7	59.3	33.9	67.8	38.1	76.3	42.4	84.8
20	176	33.0	66.0	46.2	92.4	52.8	106	59.4	119	66.0	132
22	218	40.9	81.8	57.2	114	65.4	131	73.6	147	81.8	164
24	254	47.6	95.3	66.7	133	76.2	152	85.7	171	95.3	191
27	330	61.9	124	86.6	173	99.0	198	111	223	124	248
30	404	75.8	152	106	212	121	242	136	273	152	303

Diameter of Bolt	Initial Load	Shear Capacity at ULS		Bearing Capacity- (Post Slip) at ULS kN (for end distance ≥ 3 x bolt diameter. Thickness in mm of ply passed through.										
	F_o	Single Shear	Double Shear											
mm	kN	kN	kN	5	6	7	8	9	10	12	15	20	25	30
12	61.0	37.7	75.4	65.7 (83)	78.8 (100)									
16	113	70.2	140	87.6 (111)	105 (133)	123 (155)	140 (177)							
20	176	110	219	109 (138)	131 (166)	153 (194)	175 (221)	197 249)	219 (277)					
22	218	135	271	120 (152)	145 (183)	169 (213)	193 243)	217 (274)	241 (304)	289 (365)				
24	254	158	316	131 (166)	158 (199)	184 (232)	210 (266)	237 (299)	263 (332)	315 (398)				
27	330	205	410	148 (187)	177 (224)	207 (261)	237 (299)	266 (336)	296 (373)	355 (448)	443 (560)			
30	404	251	502	164 (207)	197 (249)	230 (290)	263 (332)	296 (373)	329 (415)	394 (498)	493 (622)	638 (806)		

Notes:

Shading indicates that the ply thickness is not suitable for an outer ply. BS 4604-1 requires that in connections using preloaded bolts, no outer ply shall be smaller in thickness than half the bolt diameter or 10 mm whichever is less. Moreover, wherever possible this condition for minimum thickness shall be observed for inner plies.

A reduction for the long connection effect in accordance with Clause 14.5.5 in BS 5400-3:2000 has **not** been made.

Brackets indicate enclosed bearing.

Slip resistance is given by Clauses 14.5.4.2 and 14.5.4.4 as $\frac{F_v \times (0.9\mu)}{\gamma_m \gamma_{f3}}$ which, at SLS $= \frac{F_o \times 0.9 \times \mu}{1.2 \times 1.0}$ (F_t taken as $= 0$)

Shear resistance is given by Clause 14.5.3.4 as $\frac{0.85 \times \sigma_y \times A_{eq}}{\sqrt{2} \times \gamma_m \gamma_{f3}}$ which, for TCBs at ULS $= \frac{0.85 \times 900 \times A_{eq}}{\sqrt{2} \times 1.1 \times 1.1}$

Bearing resistance is given by Clause 14.5.3.6 as $A_{eb} \times \frac{k_1 k_2 k_3 k_4 \sigma_y}{\gamma_m \gamma_{f3}}$ which, at ULS =

$A_{eb} \times \frac{1.0 \times 2.5 \times [0.95 \text{ or } 1.2] \times 1.5 \times [355 \text{ or } 345]}{1.05 \times 1.1}$ (For S355 material, the yield strength is 355 N/mm^2 for thicknesses up to 16 mm and 345 N/mm^2 for thicknesses from 16 mm to 40 mm.)

Capacities of preloaded TCBs in standard clearance holes

BS 5400-3:2000
Grade S10T TCB
S275 & S355 material
Non-slip at ULS

Table C.8

Diameter of Bolt	Initial Load	Slip Resistance at ULS									
		$\mu = 0.25$		$\mu = 0.35$		$\mu = 0.40$		$\mu = 0.45$		$\mu = 0.5$	
	F_o	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear	Single Shear	Double Shear
mm	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN	kN
12	61.0	9.60	19.2	13.4	26.9	15.4	30.7	17.3	34.6	19.2	38.4
16	113	17.8	35.6	24.9	49.8	28.4	56.9	32.0	64.0	35.6	71.1
20	176	27.7	55.4	38.8	77.5	44.3	88.6	49.8	99.7	55.4	111
22	218	34.3	68.6	48.0	96.0	54.9	110	61.7	123	68.6	137
24	254	40.0	79.9	56.0	112	63.9	128	71.9	144	79.9	160
27	330	51.9	104	72.7	145	83.1	166	93.5	187	104	208
30	404	63.5	127	89.0	178	102	203	114	229	127	254

A reduction for the long connection effect in accordance with Clause 14.5.5 in BS 5400-3:2000 has **not** been made.

Slip resistance is given by Clauses 14.5.4.2 and 14.5.4.4 as $\frac{F_v \times (0.9\mu)}{\gamma_m \gamma_{f3}}$ which, at ULS $= \frac{F_o \times 0.9 \times \mu}{1.3 \times 1.1}$ (F_t taken as $= 0$)