

them more economic than commercial bolts. The level of tightening achieved is adequate for joint designs where developed bolt tension is not significant. Behaviour of the bolt under applied loads is well known and accepted.

Category 8.8T refers to both categories 8.8 TF and 8.8/TB

Category 8.8/TF refers to high strength structural bolts Strength Grade 8.8 used in friction type joints, fully tensioned in a controlled manner to the requirements of AS 4100.

AS 4100 specifies that friction type joints must be used where no slip is acceptable. They should also be used in applications where joints are subject to severe stress reversals or fluctuations as in dynamically loaded structures such as bridges, except in special circumstances as determined by the engineer. Where the choice is optional, bearing type joints are more economic than friction type.

Category 8.8/TB refers to high strength structural bolts Strength Grade 8.8 used in bearing type joints, fully tensioned in a controlled manner to the requirements of AS4100.

Variation in design values with bolt strength and joint design

Design values vary with joint design, bolt type and level of bolt tightening. The table below indicates the range of design values in shear which apply to bolts of the same nominal diameter (M20) in varying strength grades, used in various joint designs, in standard size holes ($K_h=1$), in accordance with AS4100.

Bolt and joint designation	Design value in shear, kN	
	Threads included in shear plane	Threads excluded from shear plane
4.6/S	44.6	62.3
8.8/S	92.6	129
8.8/TF	35.5	35.5
8.8/TB	92.6	129

*Slip factor = 0.35

Design for bolted structural joints

A summary of structural design procedures to AS 4100 has been produced by Arun Syam of Australian Institute of Steel Construction and Arthur Firkins, Consultant, and published by Ajax Spurway Fasteners in their Fasteners Handbook', pages 54 to 68.

Copies are available from AISC and Ajax Spurway Fasteners.

Design for high strength bolting

AS 4100 specifies conditions for the application of high strength structural bolts in both friction type and bearing type joints. Bolts are tightened to the same minimum induced tension in both types of joint.

Tension type joints

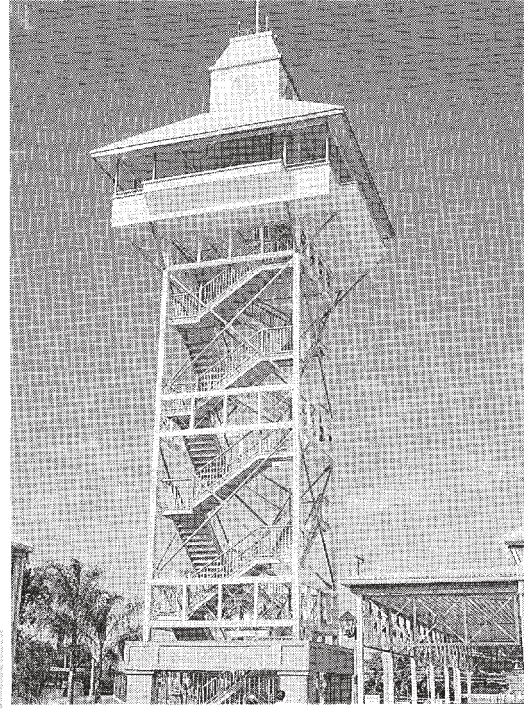
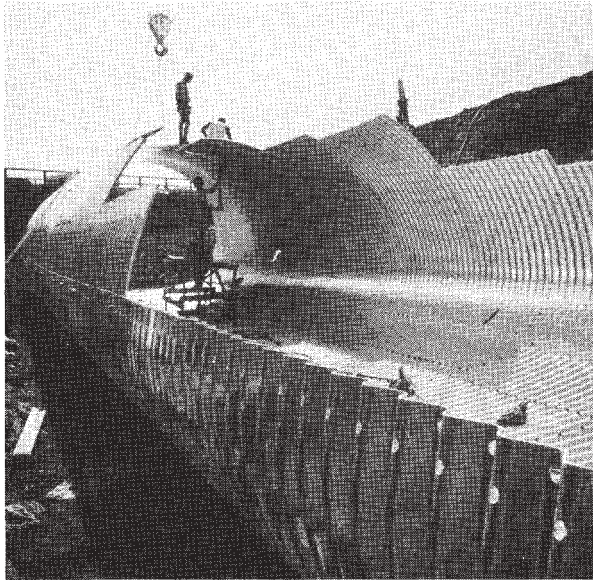
For joints in which the only force is an applied tensile force in the direction of the bolt axes, the tensile force on any bolt should not exceed 0.60 times the minimum bolt tension specified in AS 4100. Where fatigue conditions are involved the tensile force on any bolt should not exceed 0.50 times the minimum specified bolt tension.

The following table gives maximum permissible bolt tensions for both static and fluctuating loads based on the above requirements.

Nominal diameter of bolt, mm	Maximum permissible bolt tension, kN	
	Static load	Fluctuating load
M16	57	47
M20	87	72
M24	126	105
M30	201	167
M36	294	245

Bolt types and bolting categories

Bolting category	Bolt strength grade	Minimum tensile strength (MPa)	Minimum yield strength (MPa)	Name	Australian Standard	Method of tensioning/remarks
4.6/S	4.6	400	240	Commercial	AS 1111	Use snug tight. Least costly and most commonly available 4.6 grade bolt.
8.8/S	8.8	830	660	High strength structural	AS 1252	Bolts used are snug tight. The high strength structural bolt has a large bolt head and nut because it is designed to withstand full tensioning. It can also be used in a snug tight condition.
8.8/TF	8.8	830	660	High strength structural bolt, fully tensioned friction type joint	AS 1252	For categories 8.8/TF and 8.8/TB bolts are fully tensioned to the requirements of AS 4100. Cost of tensioning is an important consideration in the use of these bolting categories.
8.8/TB	8.8	830	660	High strength structural bolt, fully tensioned bearing type joint	AS 1252	

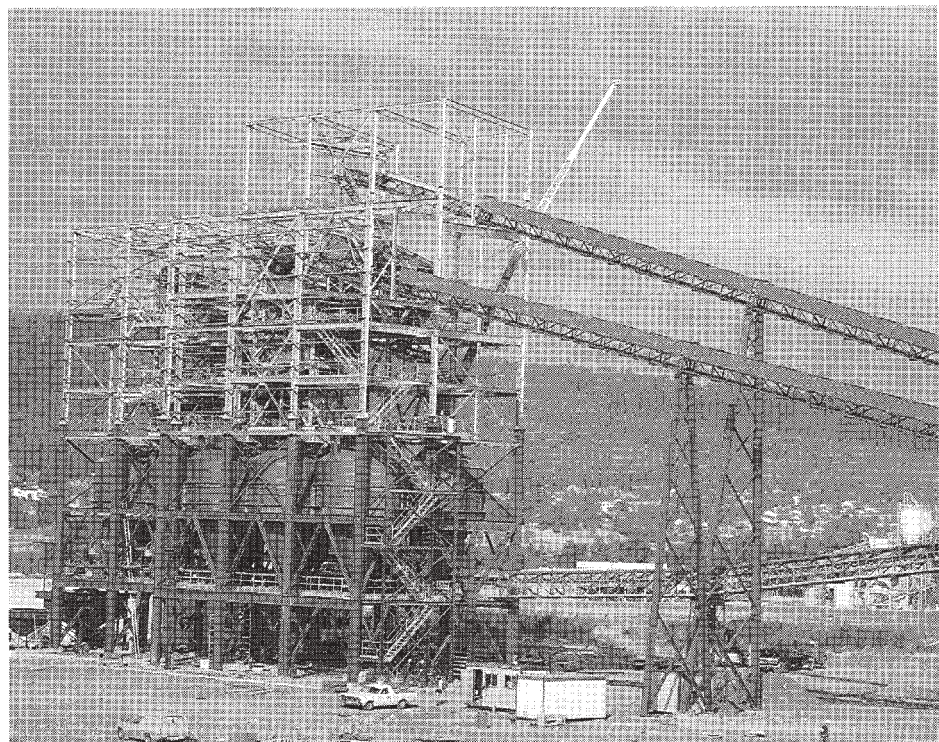
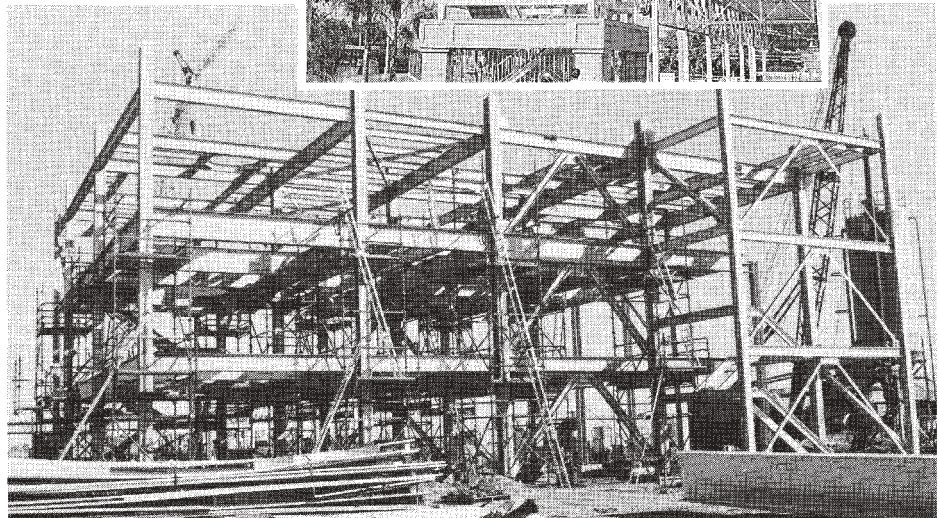


Above, corrugated multi-plate steel structures are widely used for tunnels and culverts, grade separations, caissons, and load-out tunnels, with almost any cross-section possible. Hot dip galvanizing and galvanized steel bolts and nuts ensure long life and reliability.

Top right, all steelwork in the 20-metre high Historical Observation Tower, located on Brisbane's Breakfast Creek, is vulnerable to marine exposure. The architects chose to galvanize the bolted structure and then paint, for aesthetic effect and added corrosion protection.

Chemical plant above right is of bolted, all-galvanized construction.

Right, part of a huge 600 tonnes per hour sand and gravel plant. Operator's previous experiences showed that only galvanizing stands up to wet and humid operating conditions.



Friction type joints subject to shear, and combined shear and tension.

High strength hexagon head bolts are used as described on page 52.

Shear joints

In joints subject to shear only in the plane of the friction faces the number of high strength bolts and their disposition should be such that the resulting load at any bolt position does not exceed the value:

$$\text{Slip factor}^* \times \text{number of effective interfaces} \times \text{minimum bolt tension}$$

*Slip Factor is the coefficient of friction on the mating surfaces and can be defined as the ratio of the shear force between two plies required to produce slip, to the force clamping the plies together.

AS 4100 provides that the slip factor for clean as-rolled steel surfaces shall be taken as 0.35. When protective coatings are present on mating surfaces, AS 4100 specifies that the slip factor applied in design must be that of the protective coatings, based on test evidence as discussed under 'Slip factors' page 48.

Joints subject to external tension in addition to shear

An externally applied tension in the direction of the bolt axis reduces the effective clamping action of the bolt. To allow for this effect, the Interaction Equation of AS 4100 (Rule 9.3.3.3)

$$\left(\frac{b_t}{B_t}\right) + \left(\frac{b_v}{B_v}\right) \nlessdot 1.0$$

shall apply

b_t = actual tensile force on the bolt.

B_t = maximum permissible tensile force on the bolt.

b_v = actual shear force on the bolt.

B_v = maximum permissible shear force on the bolt.

Bearing type joints subject to shear and combined shear and tension

In bearing type joints, design follows conventional practice based on allowable tension, shear and bearing values as specified in AS 4100. Design of a joint as bearing type infers that some slip into bearing may take place.

AS 4100 specifies that shear or moment connections subject to stress reversal, or where slip would not be acceptable shall be designed as friction type joints. Bearing type joints must be designed in accordance with AS 4100 using the allowable forces detailed in the table below. Provided joint surfaces are free from oil, dirt, loose scale, loose rust, burrs or defects which would prevent solid seating, AS 4100 permits the use of applied coatings without change in design values.

Joints subject to shear force only

Bearing type joints subject to shear force only, and which are less than 500 mm long in the direction of the applied shear force, shall be proportioned so that the shear force on any bolt does not exceed the maximum permissible shear force, B_v permitted by the table.

For joints greater than 500 mm long in the direction of the applied shear force, the shear force on any bolt shall not exceed the following value, whichever is appropriate:

$$500 \text{ to } 1200 \text{ mm } 6/7 B_v$$

$$1200 \text{ mm and over } 4/7 B_v$$

Joints subject to shear and tensile forces

Bearing type joints subject to shear and tensile forces shall be proportioned so that the tensile force on any bolt does not exceed that permitted by the Parabolic Interaction Equation of AS 4100 (Rule 9.3.2.3)

$$\left(\frac{b_t}{B_t}\right)^2 + \left(\frac{b_v}{B_v}\right)^2 \nlessdot 1.0$$

Maximum permissible applied forces using metric bolts to AS 1252

Diameter of bolt, mm	Maximum permissible tension: Friction type and bearing type joints B_t Note (1)	Maximum permissible applied forces bearing type joints, kN		
		Shear B_v Note (2)		
		Threaded portion	Unthreaded portion	Bearing on projected area
16	57	59	83	Refer Clause 9.3.2.4. of AS4100
20	87	93	129	
24	126	133	186	
30	201	214	291	

(1) Based on 0.6 times the minimum bolt tension shown in AS 4100. Maximum permissible stress = 0.6 proof stress, on tensile stress area A_s defined in AS 1275.

(2) Threaded portion – based on core area A_c defined in AS 1275.
Unthreaded portion – based on area of shank (nominal diameter)

Tightening procedures for high strength structural bolts

The installation and tightening of a high strength structural bolt/nut assembly is at least as costly as the bolt/nut assembly itself, and the selection of bolt type and bolt tightening procedure is an important consideration in the economics of high strength bolted structures.

Snug tightening

Snug tight is defined in AS 4100 as the full effort of a man on a standard podger spanner, or the point at which there is a change in note or speed of rotation when a pneumatic impact wrench begins impacting solidly. Podger spanners are graded in length in relation to bolt size and strength, and are, for example, of the order of 450 mm long for M20 high strength structural bolts, and 600 mm long for M24 high strength structural bolts.

Snug tightening is applied in the following situations:

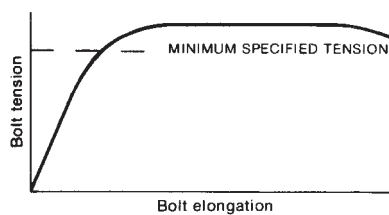
- 1 The final level of bolt tightening in general structural bolting using commercial bolts – **Category 4.6/S**.
- 2 A final level of bolt tightening using high strength structural bolts – **Category 8.8/S**. Different design values must be applied than for procedures 8.8/TF and 8.8/TB using the same bolts, as discussed on page 52.
- 3 An intermediate level of bolt tension applied as the first stage in full tightening – **Categories 8.8/TF and 8.8/TB**.

The growing popularity of high strength structural bolts to AS 1252 used in a snug tight condition leads to the situation where bolts may require full tightening to AS 4100 in one application and only snug tightening in another. **To prevent confusion and ensure correct tightening the designer must indicate clearly the level of tightening required, in both drawings and specifications.** Steps must be taken to ensure that this information is conveyed to all those involved in installation, tightening, and inspection.

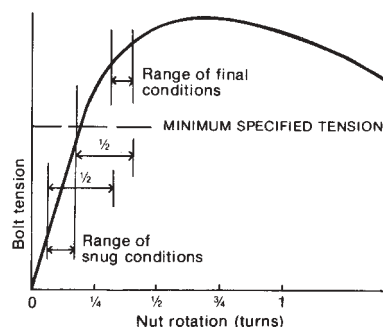
Snug tightening

When snug tightening is used as the first stage for full tightening in procedures 8.8/TF and 8.8/TB, the intention is to bring the plies into 'snug' contact ready for final tightening. The clamping force applied by snug tightening is highly variable as illustrated below, but is not significant when bolts are subsequently fully tightened – since the bolt tension/bolt elongation curve is relatively flat, variations in the snug tight condition result in only small variations in final bolt tension.

Bolt tension/bolt elongation curve for a typical high strength structural bolt.



The range of final bolt tensions after part turn tightening exceeds minimum specified bolt tension despite variability in snug tightening.



Full tightening (minimum bolt tension)

For joints designed in accordance with AS 4100, either as 8.8/TF friction type or 8.8/TB bearing type, bolts must be fully tightened to the following minimum tensions:

Nominal bolt diameter	Minimum bolt tension, kN
M16	95
M20	145
M24	210
M30	335
M36*	490

*If M36 bolts are specified the part turn method of tightening should be used only after special investigation into the capacity of the available equipment.

To attain these bolt tensions AS 4100 permits galvanized or zinc plated bolts to be tightened by either the part turn of nut method, or by the direct tension indicator method. Torque control tightening of galvanized or zinc plated bolts and nuts is prohibited in AS 4100 because of the variable torque/induced tension relationship of zinc coatings even when lubricant coated.

Nut rotation from the snug-tight condition AS 4100

Bolt length (underside of head to end of bolt)	Disposition of outer face of bolted parts Notes 1, 2, 3 and 4		
	Both faces normal to bolt axis	One face normal to bolt axis and other sloped	Both faces sloped
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 diameters	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 diameters (see Note 5)	2/3 turn	5/6 turn	1 turn

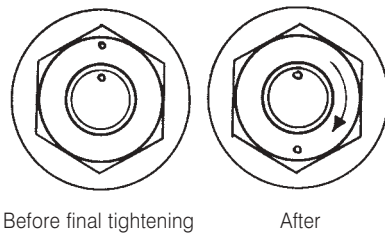
- 1 Tolerance on rotation: for 1/2 turn or less, one-twelfth of a turn (30°) over and nil under tolerance; for 2/3 turn or more, one-eighth of a turn (45°) over and nil under tolerance.
- 2 The bolt tension achieved with the amount of nut rotation specified above will be at least equal to the specified minimum bolt tension.
- 3 Nut rotation is the rotation relative to the bolt, regardless of the component turned.
- 4 Nut rotations specified are only applicable to connections in which all material within the grip of the bolt is steel.
- 5 No research has been performed to establish the turn-of-nut procedure for bolt lengths exceeding 12 diameters. Therefore, the required rotation should be determined by actual test in a suitable tension measuring device which simulates conditions of solidly fitted steel.

Part turn tightening

- 1 Line up holes with drift pins to maintain dimensions and plumbness of the structure.
- 2 Fit bolts in remaining holes. Use taper washers if surface slope exceeds 3° and use flat washers under the rotating component.
- 3 Tighten all bolts to snug tight position, progressing systematically from the most rigid part of the joint to the free edges.
- 4 On large joints take a second run to check all bolts are snug tight.

- Match mark installed nuts and bolts using a punch to show that snug tightening is complete. These marks can then be used for final tightening and inspection.

Part turn tightening. When tightening by hand or for permanent indication of tightening bolts and nuts should be match marked.

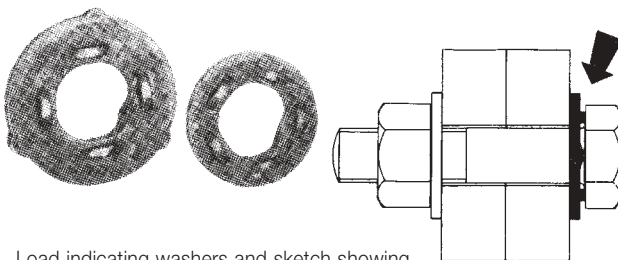


- Complete tightening using the part turn method according to the table on page 56. Tightening should proceed systematically from the most rigid part of the joint to its free edges. Wrench sockets should be marked at positions 180° apart to guide the operator in tightening.
- Knock out drift pins, replace with bolts.
- Bring these bolts to snug tight position as in step 3, match mark as in step 5 and complete tightening as in step 6.
- Mark joint to indicate tightening has been completed. One method is to draw lines with crayon between each bolt head forming a squared pattern.

Direct tension indicator tightening

Several direct tension indicating devices have been developed to provide a simple method of checking that minimum bolt tension has been developed. The most commonly used in Australia is the load indicator washer.

The load indicator is similar in size to a normal circular washer, with four to seven protrusions depending on size, on one face. It is assembled under the bolt head so that the protrusions bear on the underside of the head. As the bolt is tightened the protrusions are flattened, and reduction of the gap by a specified amount indicates that minimum bolt tension has been reached. For use with galvanized structural bolts load indicator washers are supplied with a galvanized finish.



Load indicating washers and sketch showing washer fitted under bolt head. Note gap which is reduced as nut is tightened.

Tightening procedure with load indicator washers

- Ensure that the bolts are high strength bolts to AS 1252.
- Place load indicator on the bolt with protrusions abutting the underside of the bolt head or abutting a structural flat washer if the bolt head is to be turned in tightening.
- Fit the bolt into place and assemble with nut and standard

hardened washer. If a taper washer is required it is preferable that this be fitted under the nut but alternatively it may be placed between the load indicator and the structural steel.

- Carry out a preliminary tightening to snug tight position, using a podger spanner or pneumatic impact wrench. It is important to begin tightening at the most rigid part of the joint progressing systematically to the free edges. On large joints take a second run over bolts to check that all are snug tight.
- Carry out final tightening by reducing the gap between bolt head and load indicator to approximately 0.25 mm for galvanized bolts. In aggressive exposure conditions the gap may be fully closed to exclude moisture.

Should a nut be slackened after being fully tightened a new load indicator must be fitted before the second tightening.

Fitting load indicator under nut

In applications where it is necessary to rotate the bolt head rather than the nut, the load indicator can be fitted under nut using a special nut face washer which is heat treated to the same hardness as the bolt. Care must be taken that the nut face washer is fitted concentric with the nut and the correct way up, otherwise it may turn relative to the load indicator resulting in inaccurate load indication due to damage to the protrusions.

Experience has shown that on medium to large projects the extra cost of load indicators is offset by major savings in installation, supervision, and inspection of high strength joints.

Inspection of high strength bolted joints

Because of the increasing use of high strength structural bolts in the snug tight condition the designer must clearly indicate the level of tightening required in drawings and specifications, and he must ensure that this information is conveyed to all those involved in installation, including the inspector.

In structural joints using either 4.6/S or 8.8/S procedures the site inspector need only be concerned that the correct bolt type and number of bolts have been used in the joint. Since the level of tightening required is snug tight, this would have been achieved during erection.

In joints using galvanized bolts and 8.8/TF or 8.8/TB procedures, only visual inspection is necessary. The inspector should check that the correct fasteners and washers have been used and correctly installed, and that none show physical damage which might indicate they been driven into mis-aligned holes.

Galvanized bolts which have been tightened by the part turn of nut method can be checked by their match markings. Where load indicating washers have been used for final tightening, inspection is greatly simplified.

Tightening of bolts by the torque control method has been deleted from AS 4100. For guidance on the use of a torque wrench for inspection refer to AS 4100 Supplement 1-1990, Appendix CK.

Flush spliced structural joints in galvanized steel

The increasing popularity and use of hot dip galvanizing as an architectural finish for structural steel members has sometimes been limited by the need to make structural connections. Welding, while practical, requires coating touch up which may spoil the visual continuity of the galvanized coating in some applications. Conventional bolted connections, while versatile and economic, can be visually obtrusive.

A new method of flush-splicing structural steel members conceived by Arthur Firkins, formerly Director of Technical Services, Australian Institute of Steel Construction, has been developed under the auspices of Galvanizers Association of Australia.

The new connection uses flat-head countersunk Unbrako high strength socket screws through beam flanges into threaded holes in the flange and web connecting members. The result is a flush finish to beam flange surfaces without protruding bolt heads or nuts, in a joint with the performance characteristics needed in structural applications.

Structural performance

In order to investigate joint behaviour, a test specimen was subjected to tensile testing at the University of Sydney to determine the flange force transfer capacity of a typical splice. Test results showed that the splice conformed to the requirements of Australian Standard 4100 'Steel Structures'. The test results also confirmed the designed capacity of the flange beam calculated in accordance with AS4100.

As a result of this testing, structural engineers can now incorporate unobtrusive flush-spliced structural connections, confident that their design will meet the requirements of AS4100.

Fasteners and threads

The fasteners employed are Unbrako high strength flat-head socket screws, ISO metric series, mechanically zinc plated to a coating thickness of 25µ to give adequate corrosion protection.

The specification for these bolts is:

Material:	Unbrako high-grade alloy steel*.
Hardness:	Re36-44
Ultimate tensile strength:	1100MPa
0.2% yield stress:	990MPa
Thread class:	4g.

* In the International method of designating bolt strength these bolts would be classified as Grade 10.9.

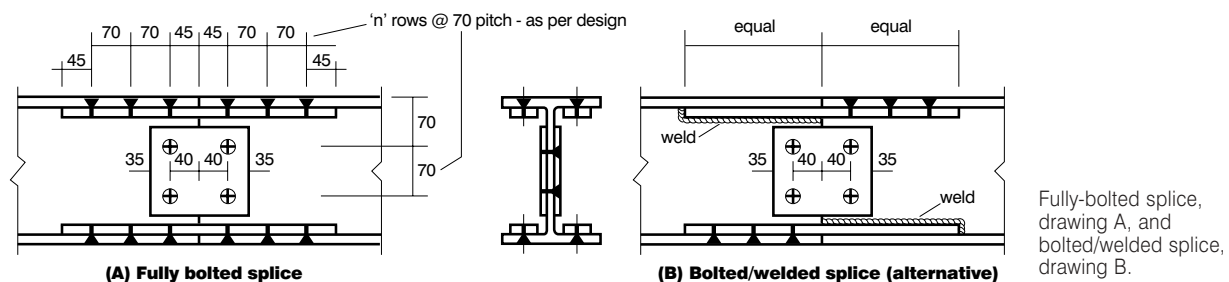
M12, M16 and M20 screw sizes are used.

Design of flush-bolted splices

Dimensional criteria for connections in commonly used beams are given in the table below. These criteria apply to both fully-bolted splices (Drawing A) and bolted/welded splices (Drawing B). This system will allow relatively large flange force transfer in members of all types and sizes. Splice plates should be at least equal to flange or web thickness and not less than screw diameter.

Installation procedures

Procedures for the installation of Unbrako socket head screws is contained in the product manual published by Unbrako.



Dimensional criteria

Size	Member		Flange plates		Web plates		Flange Size	Bolts*	Web Size
	Flange tf	Web tw	Width mm	Thick mm	Width mm	Thick mm			
UB Sections									
200 UB 30	9.6	6.3	50	20	150	6	M16		M12
250 UB 37	10.9	6.4	50	20	150	6	M16		M12
310 UB 40	10.2	6.1	50	20	150	6	M16		M12
360 UB 51	11.5	7.3	50	20	150	6	M16		M12
410 UB 54	10.9	7.6	50	20	150	8	M16		M12
460 UB 67	12.7	8.5	50	20	150	8	M20		M16
530 UB 82	13.2	9.6	75	20	150	10	M20		M16
UC Sections									
250 UC 73	14.2	8.6	100	20	150	8	M20		M16
200 UC 46	11.0	7.3	75	20	150	8	M20		M12

* Unbrako flat head socket screws Grade 10.9

- Suggested criteria in the table should be verified for specific design load cases.
- For serviceability state, "Ply in bearing (beam flange) will usually govern design" (AS4100 9.3.2.4.(2)).
- Ultimate failure in the test was the flange plate component failing in tension.
- Flange plate component thickness should be greater than flange thickness and equal to or greater than bolt diameter.
- Web plate component thickness should be greater than web thickness.
- "n" = number of rows of bolts in flange or web as required by design – see Drawing (A). Note: Bolt shear strength (10.9) will rarely govern.
- Bolts should be specified as "Unbrako flat-head socket screws Grade 10.9, mechanically zinc/tin plated to a coating thickness of 25µ".
- Holes in flange plates should be tapped 0.1mm oversize to allow for the coating thickness on screw threads.
- Tapped threads should be plugged during the galvanizing process using bolts of appropriate diameter (Grade 4.6 hex head uncoated).