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CHAPTER 4

Bolting Galvanized Steel

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Bolting Galvanized Steel

This chapter gives information on the characteristics, advantages and economics of bolted galvanized structures and zinc coated fasteners, and offers comment on bolting procedures when these are influenced by the presence of zinc coatings. All information given is in accordance with current Australian Standards, and with the rationalised approach to the design, detailing and fabrication of structural connections developed by Australian Steel Institute.

Information given is based on work carried out by Ajax Spurway Fasteners, Australian Steel Institute and International Lead Zinc Research Organization.

Bolting steel structures

Bolting has become the most widely used, versatile and reliable method of making field connections in structural steel members. The major advantages of bolting over welding are:

1. Economy, speed and ease of erection
2. Reliability in service
3. Relative simplicity of inspection
4. Fewer and less highly skilled operators required
5. Good performance under fluctuating stresses
6. Ease of making alterations and additions
7. Absence of coating damage
8. No pre-heating of high-strength steels
9. No weld cracking or induced internal stress
10. No lamellar tearing of plates.

Galvanized steel structures

In the construction of galvanized steel structures, bolted connections offer further advantages. Damage to the galvanized coating from local heating during welding is eliminated and with it the need for coating repairs to the affected area.

The high cost of maintenance labour and wide use of steel communications towers, exposed industrial structures, steel bridges and power transmission towers, often in remote areas, have made low maintenance corrosion protection systems an essential aspect of design. As a result, galvanizing has become the accepted standard for exposed steel, placing greater emphasis on bolted joints for structural steelwork and leading to development of specialised bolting techniques.

A wide range of galvanized, sherardised and zinc plated structural bolts and related fittings is available to meet any steel construction need.

Zinc coatings for fasteners

In bolted steel structures, the bolts and nuts are critical items on which the integrity of the entire structure depends.

For exterior use these critical fasteners must be adequately protected from corrosion. Where steel members of the structure are galvanized it is recommended that fasteners employed should also be galvanized or suitably zinc coated to maintain a uniform level of corrosion protection throughout the structure.

Selection of zinc coatings for fasteners

The zinc coating selected is decided primarily by the period of protection desired which should be equivalent to the life of the protective system selected for the structure.

The zinc coating process selected must also produce a relatively uniform coating over small parts of varying shape. With the thicker zinc coatings, allowances in thread dimensions must be made to accommodate the thickness of the coating.



These requirements dictate that in practice one of four types of zinc coating will be suitable:

1. Galvanizing
2. Zinc plating
3. Sherardising
4. Mechanical plating

Galvanizing

The galvanizing of fasteners produces a heavy coating of zinc ideally suitable for long-term outdoor exposure. The coating is applied by the immersion of clean, prepared steel items in molten zinc. The resulting zinc coating is metallurgically bonded to the basis steel, and consists of a succession of zinc-iron alloy layers and an outer zinc layer.

Fasteners are generally centrifuged immediately on withdrawal from the molten zinc of the galvanizing bath to remove excess free zinc and produce a smoother finish and cleaner threads.

Australian/New Zealand Standard 4680 'Hot dip galvanized (zinc) coatings on fabricated ferrous articles' provides for a standard minimum coating thickness regardless of fastener dimensions:

Requirements for coating thickness and mass for articles that are centrifuged

Thickness of articles (all components including castings) mm	Local coating thickness minimum µm	Average coating thickness minimum µm	Average coating mass minimum g/m ²
< 8	25	35	250
≥ 8	40	55	390

Note: 1. For requirements for threaded fasteners refer to AS 1214
2. 1 g/m² coating mass = 0.14µm coating thickness

Upsize tapping allowances for galvanized nuts

To accommodate the relatively thick galvanized coating on external threads, it is usual to galvanize bolts of standard thread dimensions, and to tap nuts upsize after galvanizing. AS 1214 'Hot dip galvanized coatings on threaded fasteners' specifies the following upsize tapping allowances on internal threads:

Nominal diameter of internal threads	Allowance, mm
Up to M22	0.40 mm
M24	0.45mm
M27	0.50mm
M30	0.55mm
M36	0.60mm
M36-48	0.80mm
M48-64	1.0mm

To ensure that nut stripping strength is adequate after upsize tapping, galvanized high strength nuts are manufactured from steel with a higher specified hardness than standard high strength nuts, as discussed under '[Galvanized high strength nuts](#)'.

Galvanized high strength bolts and nuts must be provided with a supplementary lubricant coating for satisfactory bolt tightening. See '[Influence of the galvanized coating on design](#)'.

Economics of galvanized coatings on bolts

Corrosion protection on bolts should match the rest of the structure and in most circumstances economics favour the use of galvanized bolts rather than painting after erection. The following table* gives indicative cost-in-place relationships for unpainted, painted, and galvanized M20 bolts in structural applications:

Bolt strength grade/ Bolting procedure	Cost-in place		
	Unpainted	Painted	Galvanized
4.6/S	100	190	110
8.8/S	120	210	140
8.8/T	170	260	190

* TJ Hogan and A Firkins, 'Bolting of steel structures' Australian Institute of Steel Construction

Zinc plating

Zinc plating on fasteners produces relatively light, uniform coatings of excellent appearance which are generally unsuitable for outdoor exposure without additional protection.

There is in general an economic upper limit to the coating mass which can be applied by plating, although certain specialised roofing fasteners are provided with zinc plated coatings up to 35 to 40 µm thick. Where heavy coatings are required galvanizing is usually a more economic alternative.

Zinc plated bolts having a tensile strength above 1000 MPa must be baked for the relief of hydrogen embrittlement.

Zinc plated high strength bolts and nuts must be also provided with a supplementary lubricant coating to provide for satisfactory bolt tightening. See [‘Torque/induced tension relation in tightening’](#).

Australian standards for zinc plating require that one of a range of chromate conversion coatings be applied in accordance with Australian Standards 1791 ‘Chromate conversion coating on zinc and cadmium electrodeposits’. Clear, bleached, iridescent or opaque films may be produced, depending on the level of resistance to wet storage staining required.

Australian Standard 1897 ‘Electroplated coatings on threaded components (metric coarse series)’ specifies plating thicknesses which can be accommodated on external threads to required tolerances.

Sherardising

Sherardising produces a matt grey zinc-iron alloy coating. The process impregnates steel surfaces with zinc by rumbling small components and zinc powder in drums heated to a temperature of about 370°C. The least known of the various processes for zinc coating steel, sherardising is not used in Australia. The process is characterised by its ability to produce a very uniform coating on small articles.

The thickness of sherardised coatings is generally of the order of 15µm but can vary depending on cycle time from 7.5 to 30µm. Sherardised coatings therefore fall between zinc plated and galvanized coatings in thickness and life.

Although sherardising is an impregnation process there is some build up in dimensions. British Standard 729 ‘Zinc coatings on iron and steel articles, Part 2: Sherardised coatings’ recommends an oversize tapping allowance of 0.25mm on nuts to ensure easy assembly with sherardised bolts.

Mechanical (peen) plating

Mechanical or peen plating offers advantages in the zinc coating of fasteners. Coatings are uniform, and because the process is electroless there is no possibility of hydrogen embrittlement. High strength fasteners not susceptible to embrittlement need not be baked after coating. Lubricant coatings must be applied to ensure satisfactory tightening.



Influence of the galvanized coating on design

The presence of either galvanized coatings or zinc plating on high strength bolts, and galvanized coatings on structural members may need to be taken into account in design. The following factors should be considered:

1. Slip factors of mating surfaces
2. Fatigue behaviour of bolted galvanized joints
3. Bolt relaxation
4. Effect of galvanized coating on nut stripping strength
5. Torque/induced tension relation in bolt tightening

1. Slip factors affecting mating surfaces

In a friction type bolted joint all loads in the plane of the joint are transferred by the friction developed between the mating surfaces. The load which can be transmitted by a friction type joint is dependant on the clamping force applied by the bolts and the slip factor of the mating surfaces.

Australian Standard 4100 'Steel structures' assumes a slip factor of 0.35 for clean as-rolled steel surfaces with tight mill scale free from oil, paint, marking inks and other applied finishes. AS 4100 permits the use of applied finishes such as galvanizing in friction type joints, but requires that the slip factor used in design calculations be based on test evidence in accordance with the procedures specified in Appendix J of the standard. Tests on at least three specimens are required, but five is preferred as the practical minimum.

Bearing type joints are not affected by the presence of applied coatings on the joint faces, so galvanizing may be used without affecting design strength considerations.

Slip factors of galvanized coatings

Research conducted in Australia and overseas shows mean slip factors for conventional galvanized coatings over a large number of tests to be in the range 0.14 to 0.19, as compared to 0.35 for clean as-rolled steel.

Design values take these lower slip factors into account, and galvanized steel is used widely in high strength friction type joints.

Work by Professor WH Munse* for International Lead Zinc Research Organization, and others, shows that the slip factors of galvanized surfaces can be substantially improved by treatments such as wire brushing, light 'brush off' grit blasting, and disc abrading. In each case the treatment must be controlled to provide the requisite scoring or roughening to expose the alloy layers of the coating. Care must be taken to ensure that excessive coating thickness is not removed.

The following table shows the results of slip factor testing various galvanized surfaces in four-bolt joints.

Surface Treatment	No. of tests	Average	Min	Max
As received	15	0.14	0.11	0.18
Weathered	3	0.20	0.15	0.26
Wire brushed	4	0.31	0.27	0.33
Grit blasted	2	0.31	0.28	0.34

* WH Munse 'High strength bolting of galvanized connections' presented to the symposium 'Bolting galvanized connections and new steel design specifications', Australian Institute of Steel Construction and Australian Zinc Development Association, 1968

It is important to recognise more recent developments in galvanizing technology which produce harder final layers of zinc. Testing has been undertaken to establish higher slip factors for structural steel produced in the modern galvanizing facilities. Designers should check with the galvanizer before assuming a slip factor for slip critical joints in a structure.

Fully alloyed 'grey' galvanized coatings which can result from the galvanizing of silicon steels have also been shown to develop higher slip factors.

Slip factors given here are indicative only, and designs must be based on proven slip factors established by testing in accordance with the requirements of AS4100, Appendix J.

2. Fatigue behaviour of bolted galvanized joints

While the galvanized coating behaves initially as a lubricant it has been shown in fatigue tests carried out by Munse that after the first few cycles galvanized mating surfaces tend to 'lock up' and further slip under alternating stress is negligible. The figure below taken from work by Munse illustrates this effect. Note the rapidly decreasing amplitude of slip from first to second and then to fifth stress cycle.

Further indications of 'lock up' behaviour became apparent when joints were disassembled, galling of the galvanized coating being observed in regions where there had been high contact pressure. Where no initial slip can be tolerated a reduced slip factor must be used in design. The slip factor of the galvanized coating may be improved by wire brushing or 'brush off' grit blasting as discussed above, but slip factors for galvanized surfaces post treated in this way must be verified in accordance with Appendix J of AS 4100.

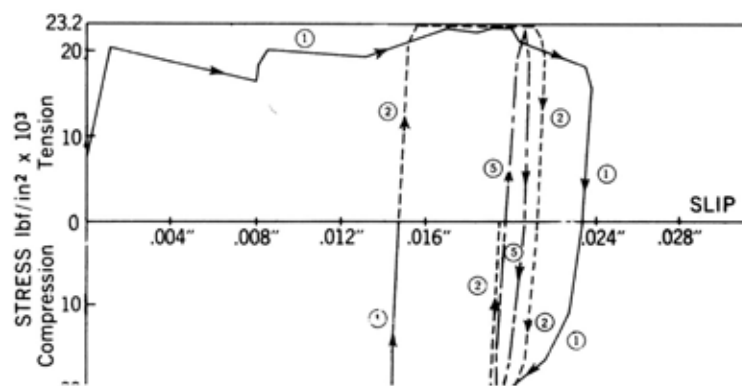
3. Bolt relaxation

The possible effect of bolt relaxation caused by the relatively soft outer zinc layer of the galvanized coating on the member must also be considered. If the zinc coating flowed under the high clamping pressure it could allow loss of bolt extension and hence tension. This factor was also studied by Munse. He found a loss of bolt load of 6.5 percent for galvanized plates and bolts due to relaxation, as against 2.5 percent for uncoated bolts and members. This loss of bolt load occurred in 5 days and little further loss is recorded. This loss can be allowed for in design and is readily accommodated.

4. Effect of galvanized coatings on nut stripping strength

Galvanizing affects bolt-nut assembly strength primarily because the nut must be tapped oversize to accommodate the thickness of the zinc coating on the bolt thread. The oversize tapped thread reduces the stripping strength of the nut when tested on a standard size threaded mandrel.

In high strength bolting correct tightening is essential and Australian Standard 1252 'High strength steel bolts with associated nuts and washers' makes no exceptions for oversized tapped galvanized nuts and specifies that all high strength nuts must meet the full stripping load when tested on a standard-size hardened mandrel. To meet this requirement galvanized high strength nuts must have a higher specified hardness in accordance with AS 1252. For this reason normal high strength nuts must not be galvanized and tapped oversize for use in high strength bolted joints.



Stress versus slip for fatigue specimen subjected to alternating stress of 23.2 kips/in² Galvanized members and bolts. First, second and fifth stress cycles. WH Munse "Structural Behaviour of hot galvanized bolted connections". Proceedings 6th International Conference on Hot Dip Galvanizing 1968.

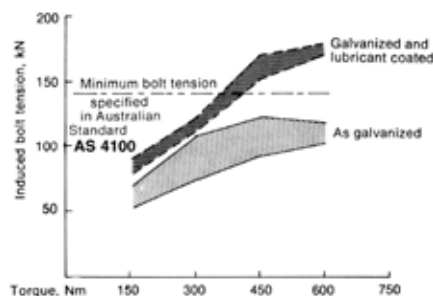


5. Torque/induced tension relation in tightening

The relationship between torque and induced tension in tightening is dependent on bolt and nut thread surface finish, thread surface coatings, and conditions of lubrication.

Galvanized coatings and zinc plated coatings on threads both increase friction between the bolt and nut threads, and make the torque/induced tension relation much more variable.

The effect of lubricants on galvanized or zinc plated threads is significant. The torque/tension relationship shows much reduced variability, and it becomes possible to tighten in excess of the minimum tension without danger of bolt fracture.



Torque/induced tension-relation for M20 high strength structural bolts, galvanized and lubricant coated, and as-galvanized.

The diagram shows the torque/induced tension relation for as-galvanized, and lubricant coated galvanized M20 high strength structural bolts. With the as-galvanized assemblies there is a wide scatter in induced tension at any one torque level and torque could not be used to provide a reliable method for gauging the required minimum bolt tension specified in AS 4100 before bolt fracture occurred. Bolt failures in torsion resulted from the high friction between the as-galvanized bolt and nut threads. Accordingly, AS 4100 does not recognise the use of the torque control method for tensioning galvanized or zinc plated bolts, as discussed under **'Full tightening'**.

Lubricated coatings on threads

Because of the poor torque/induced tension relationship of galvanized or zinc plated high strength bolt/nut assemblies AS 1252 specifies that supplementary lubrication must be provided. Lubricants should be pre-applied by the manufacturer.

Effectiveness of lubricants is checked by an assembly test which requires the bolt to withstand a minimum of between 180° and 420° from a snug position, depending on bolt length, before bolt fracture occurs.

Even when lubricant coated, galvanized and zinc plated high strength bolt/nut assemblies produce a wide scatter in induced tension for a given level of torque during tightening. Therefore only part-turn tightening or direct tension indicator tightening methods may be used as discussed under **'Part-turn tightening'** and **'Direct tension indicator tightening'**.

Structural bolts and bolting techniques

Three main types of metric bolt are used in structural engineering in Australia:

- **Commercial bolts** to AS 1111, strength grade 4.6
- **Medium strength or tower bolts** to AS 1559, strength grade 5.6
- **High strength structural bolts** to AS 1252, strength grade 8.8

Design provisions for structural bolts are contained in Australian Standard 4100-1998 'Steel structures'. This standard, in limit states design format, supersedes AS 1250 which was in a working stress format. AS 4100 also incorporates the design and installation clauses of high strength bolts from AS 1511 which it also supersedes.

Relevant Australian Standards

Relevant material standards referenced by Australian Standard 4100 are the current editions of:

AS 1110	'ISO metric hexagon precision bolts and screws'
AS 1111	'ISO metric hexagon commercial bolts and screws'
AS 1112	'ISO metric hexagon nuts, including thin nuts, slotted nuts and castle nuts.'
AS 1252	'High strength steel bolts with associated nuts and washers for structural engineering'
AS 1275	'Metric screw threads for fasteners'
AS 1559	'Fasteners – bolts, nuts and washers for tower construction'

Strength designations, metric bolts

The strength of metric structural bolts is specified in terms of the tensile strength of the threaded fastener and defined according to the ISO strength grade system which consists of two numbers separated by a point, for example 4.6. The first number of the designation represents one hundredth of the nominal tensile strength (MPa) and the number following the point represents the ratio between nominal yield stress and nominal tensile strength.

For example a Property Class 4.6 bolt has:

Tensile strength of $4 \times 100 = 400$ MPa

Yield stress of $0.6 \times 400 = 240$ MPa

Galvanized commercial grade bolts

Metric commercial grade low carbon steel bolts used in the structural steel industry are manufactured to Australian Standard 1111 'ISO metric hexagon commercial bolts and screws' which calls for a tensile strength of 400 MPa minimum, with the Property Class designation 4.6. Design stresses are specified in AS 4100.

Identification of commercial bolts

Commercial bolts Property Class 4.6 carry the maker's name and the metric M on the bolt head. Nuts generally are supplied to Strength Grade 5 and carry no markings.

Galvanized tower bolts

Transmission towers are designed as critically stressed structures and the very large number of towers used provided the incentive to reduce weight and cost by application of the plastic theory basis for design. This design concept calls for a higher strength bolt than the standard commercial 4.6 bolt. The medium strength tower bolt to Australian Standard 1559 'Fasteners – bolts, nuts and washers for tower construction' was developed to meet this need. Property Class is 5.6 and galvanizing is the standard finish to provide corrosion protection matched to the structure.

As maximum shear strength values are required the thread is kept out of the shear plane. Transmission towers are often erected in high snow country and it is also necessary to have a bolt with good low temperature notch toughness. Short thread lengths and specified notch ductility meet these requirements.

AS 1559 calls for the following properties:

Tensile strength minimum	480 MPa
Yield stress, minimum	340 MPa
Stress under proof load	320 MPa
Charpy V-notch impact at 0°C:	
Average of 3 tests, minimum	27J
Individual test, minimum	20J



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Nut locking of tower bolts

Transmission towers are constructed from galvanized structural sections using single bolted joints, and positive prevention of nut loosening is necessary in critical situations. This requirement is met by effective initial tightening and some additional measure to ensure nut locking, such as punching and distortion of the bolt thread at the outer nut face after tightening, or the use of galvanized prevailing torque type lock nuts.

Identification of tower bolts

Galvanized metric tower bolts carry the metric M on the bolt head together with the letter T for Tower, and the maker's name. Property Class 5 nuts are normally used, without markings.

Galvanized high strength structural bolts

The use of high strength structural bolts to AS 1252 in appropriate structural designs provides improved economy and efficiency in the fabrication of galvanized structures by permitting:

1. Smaller bolts of higher strength
2. Fewer bolts and bolt holes, resulting in:
3. Lower fabrication cost for members
4. Faster erection and reduced erection cost

AS 1252 calls for the following properties

Tensile strength, minimum	830 MPa
Yield stress, minimum	660 MPa
Stress under proof load	600 MPa
Minimum breaking load:	
M20 nominal diameter	203 kN
M24 nominal diameter	293 kN

In structural applications galvanized high strength structural bolts are commonly used in M20 and M24 metric diameter in both flexible and rigid connections. M30 diameter is less used in structural applications, particularly when full tightening is required to AS 4100, because of the difficulty of on-site tensioning to achieve specified minimum bolt tensions. M36 should never be specified if full tensioning to AS 4100 is required.

Galvanized high strength nuts

Nut threads are tapped oversize after galvanizing to allow for the increased thread diameter of the galvanized bolt. To ensure that nut stripping strength is adequate after oversize tapping, galvanized high strength nuts are manufactured from steel with a higher specified hardness than other high strength nuts, as discussed under '[Oversize tapping allowances for galvanized nuts](#)'.

AS1252 specifies the following mechanical properties

Nut type	Proof load stress MPa	Rockwell hardness HRC		HRB	Vickers hardness HV	
		Max	Min		Max	Min
Galvanized	1165	36	24	-	353	260
All others	1075	36	-	89	353	188

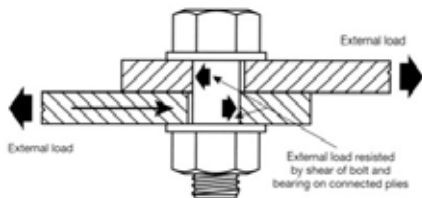
Identification of high strength bolts, nuts and washers

Galvanized high strength bolts to AS 1252 Property Class 8.8 can be identified by three radial lines on the bolt head, with the maker's name and the metric M. Nuts to Property Class 8 for use with structural bolts can be identified by three circumferential lines on the face of the nut. Relative to nominal thread size, high strength structural bolt heads and nuts are visibly larger than commercial bolts and nuts. Flat round washers for use with high strength structural bolts can be identified by three circumferential nibs.

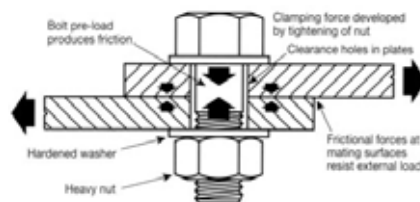
Modes of force transfer in bolted joints

In the design of individual bolts in bolted structural connections, there are three fundamental modes of force transfer:

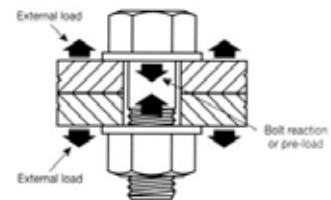
- 1. Shear/bearing mode.** Forces are perpendicular to the bolt axis and are transferred by shear and bearing on the connecting plies – bolting categories 4.6/S, 8.8/S and 8.8/TB described below.



- 2. Friction mode.** Forces to be transferred are perpendicular to the bolt axis as in shear/bearing mode, but load carrying depends on the frictional resistance of mating surfaces – bolting category 8.8/TF



- 3. Axial tension mode.** Forces to be transferred are parallel to the bolt axis – may apply in combination with other bolting categories.



Bolting category system

The following bolting category identification system is based on that used in AS4100:

Category 4.6/S – Commercial bolts used snug tight

Category 8.8/S – High strength structural bolts used snug tight

Category 8.8/TF – High strength structural bolts fully tightened in friction type joints

Category 8.8/TB – High strength structural bolts fully tightened in bearing type joints

This category designation system is derived from the Strength Grade designation of the bolt, for example 8.8, and the bolting design procedure which is based on the following supplementary letters:

S represents snug tight

TF represents fully tensioned, friction type joint

TB represents fully tensioned, bearing type joint

Category 4.6/S refers to commercial bolts of Strength Grade 4.6 tightened snug tight as described under **'Tightening procedures' for high strength structural bolts.**

(Snug tight is the final mode of tightening for bolting categories 4.6/S and 8.8/S, and the first step in full tensioning for bolting categories 8.8/TF and 8.8/TB).

Category 8.8/S refers to high strength structural bolts of Strength Grade 8.8 used snug tight.

High strength structural bolts in the snug tight condition may be used in flexible joints where their extra capacity can make 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 AS 4100.

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 AS 4100

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

Design for bolted structural joints

A summary of structural design procedure to AS 4100 has been produced by the Australian Steel Institute.

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 the following table.

Maximum permissible bolt tension, kN

Nominal diameter of bolt, mm	Static load:
M16	104
M20	163
M24	234
M30	373

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 as 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	

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

High strength hexagon head bolts are used as described under '**Galvanized high strength structural bolts**'.

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:

Slip factor* x number of effective interfaces x 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 of galvanized coatings**'.

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)

$$\left(\frac{V_{sf}^*}{\phi V_{sf}} \right) + \left(\frac{N_{tf}^*}{\phi N_{tf}} \right) \leq 1.0$$

Where:

V_{sf}^* = design shear force on the bolt in the plane of the interfaces

N_{tf}^* = design tensile force on the bolt

ϕ = capacity factor

V_{sf} = nominal shear capacity of the bolt

N_{tf} = nominal tensile capacity of 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, permitted by the table.

For joints greater than 500 mm long refer to clause 9.3.2.1 of AS 4100.

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)

$$\left(\frac{V_f^*}{\phi V_f} \right)^2 + \left(\frac{N_{tf}^*}{\phi N_{tf}} \right)^2 \leq 1.0$$

Where:

ϕ = capacity factor

V_f = nominal bolt shear capacity

N_{tf} = nominal tensile capacity of the bolt

Maximum permissible applied forces using metric bolts to AS 1252

Diameter of bolt, mm	Maximum permissible tension: Friction type and bearing type joints	Maximum permissible applied forces bearing type joints, kN		
		Shear note (1)		Bearing on projected area
		Threaded portion	Unthreaded portion	
16	104	59	83	Refer Clause 9.3.2.4 of AS 4100
20	163	93	129	
24	234	133	186	
30	373	214	291	

Note (1) 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 450mm long for M20 high strength structural bolts, and 600mm 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 in **'Variation in design values with bolt strength and joint design'**.
3. An intermediate level of bolt tension applied as the first stage in full tightening – **Categories 8.8/TF and 8.8/TB**.

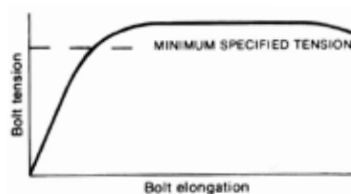
The growing popularity of high strength structural bolts to AS 1252 used in a snug tight condition leads to the situation where bolts may require full tightening to AS 4100 in one application and only snug tightening in another.

To prevent confusion and ensure correct tightening the designer must indicate clearly the level of tightening required, in both drawings and specifications.

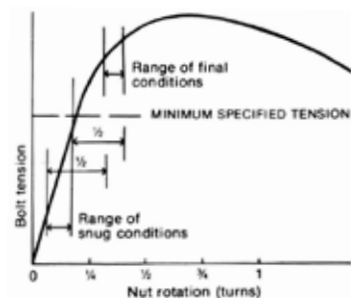
Steps must be taken to ensure that this information is conveyed to all those involved in installation, tightening and inspection.

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

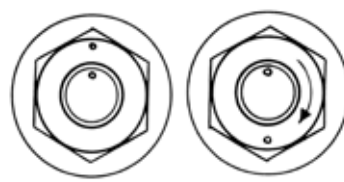
	Disposition of outer face of bolted parts Notes 1, 2, 3 and 4		
Bolt length (underside of head to end of bolt)	Both faces normal to bolt axis	One face normal to bolt axis and other sloped	Both faces sloped
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8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

Note:

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.
5. 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.



Before final tightening

After

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

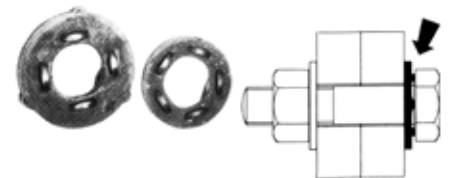
6. Complete tightening using the part turn method according to the table on page 56. Tightening should proceed systematically from the most rigid part of the joint to its free edges. Wrench sockets should be marked at position 180° apart to guide the operator in tightening.
7. Knock out drift pins, replace with bolts
8. Bring these bolts to snug tight position as in step 3, match mark as in step 5 and complete tightening as in step 6.

9. 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 fitted under bolt head. Note gap which is reduced as nut is tightened.

Tightening procedure with load indicator washers

1. Ensure that the bolts are high strength bolts to AS 1252
2. 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.
3. 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.



4. 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.
5. 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 have 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 1-1999, Appendix CK.

Flush spliced structural joints in galvanized steel

The increasing popularity and use of hot dip galvanizing as a stand alone or bare finish for structural steel members means that a consistency in the overall finish is desirable. This can be affected by the type of connections used. Welding, while practical, requires coating touch up which may spoil the visual continuity of the galvanized coating in some applications. Conventional bolted connections, are versatile and economic as is the method of flush splice connections.

A method of flush-splicing structural steel members was conceived by Arthur Firkins, formerly Director of Technical services, Australian Institute of Steel Construction.

The 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 AS 4100. 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 AS 4100.

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 25µm 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

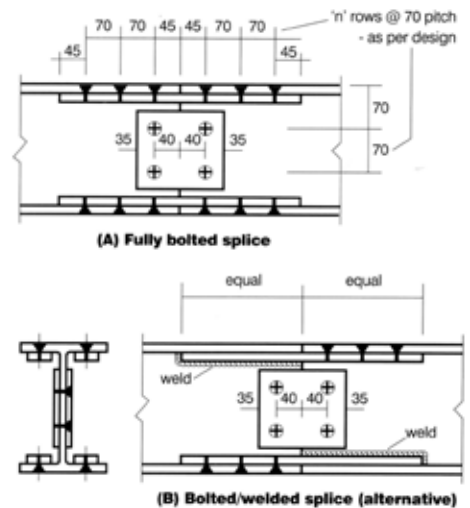
M12, M16 and M20 screw sizes are used.

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.



Fully-bolted splice, drawing A, and bolted/welded splice, drawing B.

Dimensional criteria

Size	Member		Flange plates		Web plates		Bolts*	
	Flange tf	Web tw	Width mm	Thick mm	Width mm	Thick mm	Flange Size	Web Size

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

1. Suggested criteria in the table should be verified for specific design load cases.
2. For serviceability state, "Ply in bearing (beam flange) will usually govern design" (AS 4100 9.3.2.4(2)).
3. Ultimate failure in the test was the flange plate component failing in tension.
4. Flange plate component thickness should be greater than flange thickness and equal to or greater than bolt diameter.
5. Web plate component thickness should be greater than web thickness.
6. "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.
7. Bolts should be specified as "Unbrako flat-head socket screws Grade 10.9, mechanically zinc/tin plated to a coating thickness of 25µm".
8. Holes in flange plates should be tapped 0.1mm oversize to allow for the coating thickness on screw threads.
9. Tapped threads should be plugged during the galvanizing process using bolts of appropriate diameter (Grade 4.6 hex head uncoated).