APG GALVANIZING

galvanizers ASSOCIATION OF AUSTRALIA

Best Practice Guide for Hot Dip Galvanized Bolts and Bolted Joints

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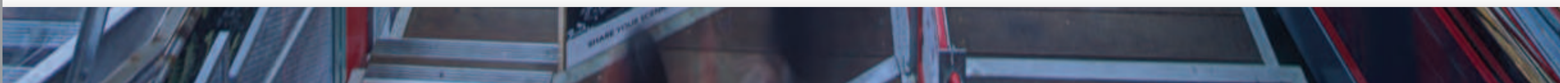

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***Front Cover:** The 2013 rebuild of the Scenic Railway in the Blue Mountains, NSW made extensive use of hot dip galvanized bolts including joining of galvanized and painted structural steel elements.*

galvanizers

Figure 1: Roadside barriers come in all sizes and shapes, with this HDG crash barrier and sculpture bolted directly onto the concrete wall on this overpass in Queensland

Hot dip galvanized (HDG) bolts, nuts and washers are widely accepted as the most economical, reliable, and easy to use structural fasteners.

Introduction

Hot dip galvanized (HDG) bolts, nuts and washers are widely accepted as the most economical, reliable, and easy to use structural fasteners. They are used to connect galvanized, painted, and uncoated structural steel and other steel products.

This best practice guide includes information on the characteristics, advantages, and economics of bolted structures and hot dip galvanized fasteners, as well as offering comment on bolting procedures when these are influenced by the presence of zinc coatings. Information provided is in accordance with current Australian and International Standards, and with the rationalised approach to the design, detailing and fabrication of structural connections developed by the Australian Steel Institute.

The information in this guide has been developed from work previously published by the Galvanizers Association of Australia, along with more recent publications by the Australian Steel Institute and the International Zinc Association. This edition of the guide also includes the results of the latest international research on slip factors for hot dip galvanized connections.

Bolted steel structures

Bolted joints comprise fasteners secured in place by mating threads, to connect or attach parts of a structure together. Bolting is the major alternative to welding for connecting structural steel and has become the most widely used, versatile and reliable method of making field connections in structural steel members.

In bolted steel structures the bolts, nuts and washers 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 preferable that fasteners employed should also be galvanized or suitably zinc coated to maintain a uniform level of corrosion protection throughout the structure.

Figure 2: HDG fasteners are used in this domestic application to join both light steel purlins and structural columns to the portal frame (Cut Paw Paw by Andrew Maynard Architects, Photo by Tess Kelly)

Bolting in hot dip galvanized steel structures

In the construction of steel structures, bolted connections offer significant advantages over other construction methods. For galvanized structures, bolted connections eliminate the damage that occurs from local heating of the surface during on-site welding 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, steel framed buildings, industrial structures, steel bridges and power transmission (often in remote areas) have made low maintenance corrosion protection systems an essential aspect of design. As a result, hot dip 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 hot dip galvanized, sherardised and zinc plated structural bolts and related fittings are available to meet any steel construction need.

Another advantage of bolted connections are their viability in a circular economy in the re-use phase, as they allow the original structure to be designed in modules leading to smaller, transportable, demountable structures which are suited for galvanizing and re-galvanizing and therefore are more sustainable than other coatings.

10 advantages of bolted connections	
1	Support for the circular economy through the re-use of components including alterations and additions
2	Cost, speed, and ease of erection
3	Reliability in service
4	Relative simplicity of inspection
5	Fewer and less highly skilled operators required
6	Good performance under fluctuating stresses
7	No damage to the coating
8	No pre-heating of high-strength steels
9	No weld cracking or induced internal stress
10	No lamellar tearing of plates

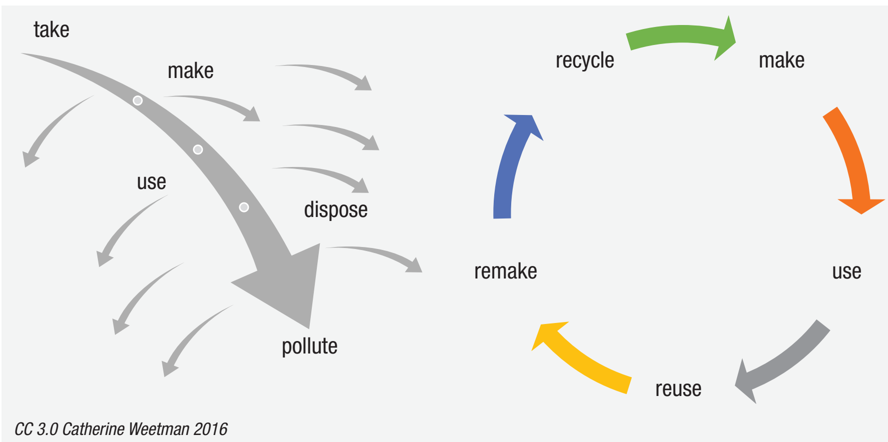


Figure 3: The traditional linear economy versus the more sustainable circular economy

Australian Standards for bolting

Design and construction Standards

The **design** provisions for structural bolts are contained in four major Standards. While the design provisions are usually consistent across the Standards, the specifier should check against the provisions in the relevant Standard.

- AS/NZS 2327, *Composite structures — Composite steel-concrete construction in buildings* (1), which covers the design, detailing and construction of composite steel-concrete members (beams, columns, slabs, joints) in buildings
- AS 4100, *Steel structures* (2), which covers the design of buildings, structures and cranes constructed of steel
- AS/NZS 4600, *Cold-formed steel structures* (3), which is used for the design of structural members cold-formed to shape from carbon or low-alloy steel sheet, strip, plate or bar not more than 25 mm in thickness and used for load-carrying purposes in buildings (bolting procedures in this guide relevant for steel thicknesses ≥ 3mm)
- AS/NZS 5100.6, *Bridge design, Part 6: Steel and composite construction* (4), which is used for the design of road, railway and pedestrian bridges, including the design of box and longitudinally stiffened girders

The **construction** requirements of structural steelwork involving fabrication, corrosion protection, erection, and modification of steelwork, including detailed provisions for bolted assemblies is covered in a single Standard.

- AS/NZS 5131, *Structural steelwork – fabrication and erection* (5)

Fastener standards

There are four types of structural bolts referenced in Standards and used in Australia. Several of these have been the subject of major revisions in recent years, including AS/NZS 1252 (6), which now incorporates elements of the EN14399 series (7) allowing for strength grade 8.8HR and strength grade 10.9HR assemblies, along with more traditional commercial and high strength grades.

- Commercial bolts to AS 1111.1 (8), strength grade 4.6
- High strength structural bolts to AS/NZS 1252.1, strength grade 8.8
- High strength structural bolts to AS/NZS 1252.1, strength grade 10.9
- Tower bolts to AS 1559 (9), strength grade 5.6

Specialised fasteners such as stud, footing, and anchor bolts are also covered in some of the design Standards. The properties of these fasteners are often as per the common strength grades. The GAA can provide further information as required.

Table 1: Key structural fastener standards

Standard	Name		International Equivalent
AS 1110	ISO metric hexagon bolts and screws – Product grades A and B		
	Part 1	Bolts	ISO 4014
	Part 2	Screws	ISO 4017
AS 1111	ISO metric hexagon bolts and screws – Product grades C		
	Part 1	Bolts	ISO 4016
	Part 2	Screws	ISO 4018
AS 1112	ISO metric hexagon nuts		
	Part 1	Style 1 – Product grades A and B	ISO 4032
	Part 2	Style 2 – Product grades A and B	ISO 4033
	Part 3	Product grade C	ISO 4034
	Part 4	Chamfered thin nuts – Product grades A and B	ISO 4035
AS 1237.1	Plain washers for metric bolts, screws, and nuts for general purposes		
	Part 1	General plan	ISO 887
AS/NZS 1252	High strength steel fastener assemblies for structural engineering – Bolts, nuts, and washers		
	Part 1	Technical requirements	
	Part 2	Verification testing for bolt assemblies	
AS 1275	Metric screw threads for fasteners		
AS 1559	Hot dip galvanized steel bolts with associated nuts and washers for tower construction		
AS 4291	Mechanical properties of fasteners made of carbon steel and alloy steel		
	Part 1	Bolts, screws, and studs	ISO 898-1
	Part 2	Nuts with specified property classes – Coarse thread and fine pitch thread (AS/NZS edition)	ISO 898-2

Where not referenced in this document, full details of the Standards listed here can be obtained from https://www.standards.org.au/.

A major revision to AS/NZS 1252 in 2016 facilitated improved compliance outcomes for high strength bolts. Other changes to that Standard aimed to move towards a bolt specification that was aligned with global supply. AS/NZS 1252 now consists of two parts (technical requirements and verification testing). Part 1 includes the following major changes to the technical requirements:

- **Dimensional changes and designation**.
- **Bolt assembly functional characteristics** – introduces a new section, *Bolting Assemblies*, including the minimum bolt tension for various diameter bolts as well as the minimum nut rotation requirement. This new section finishes off defining the relationship between torque applied to the nut (or bolt) and the tensions developed in the bolting assemblies.
- **Bolt assembly test** – essentially demonstrates if the bolt assembly can be tightened to meet the required minimum tension.
- **Identification, certification, and testing** – introduces a new section, *Identification, certification, and testing*, which covers the required identification of the product on the packaging, the testing and test report required and the requirement for a declaration of conformity from the manufacturer.
- **Product conformity** – introduces a new Appendix, *Product Conformity*, which gives information about the minimum required sampling and test plans to demonstrate product conformity.
- **Alternative assembly type** – allows the use of EN 14399-3 System HR property class 8.8 bolt assemblies as the only alternative assembly type deemed to satisfy AS/NZS 1252.1.
- **Additional assembly type** – incorporates an assembly type to EN 14399-3 System HR property class 10.9 bolt assemblies as an *additional assembly type* in AS/NZS 1252.1.

Hot dip galvanizing Standard for fasteners (bolts, nuts, and washers)

AS/NZS 1214, *Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series)* (10) is the Standard used to specify hot dip galvanized coatings on structural fasteners. This Standard was modified in 2016 to align with the international Standards and to support the changes to AS/NZS 1252. It provides users with simpler specification and purchasing arrangements consistent with international norms. The new AS/NZS 1214 is essentially an adoption of ISO 10684 (11).

Throughout this document references to hot dip galvanized fasteners assume that hot dip galvanizing is carried out to AS/NZS 1214.

AS/NZS 1214 provides users with simpler specification and purchasing arrangements consistent with international norms.

Figure 4: Hot rolled sections and hollow sections can be easily joined with bolted connections

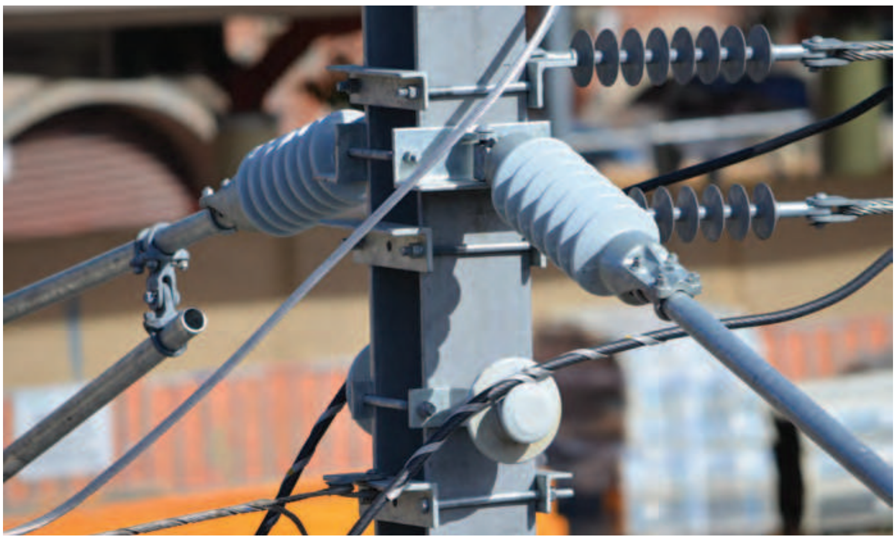


Figure 5: Electrical installations on critical infrastructure often use hot dip galvanized bolted connections

Structural fasteners and bolting techniques

Connections are made up of components (cleats, gussets, brackets, and plates) and connectors (bolts, pins, and welds). This guide only deals with bolted connections. It is critical in the design of structural connections that the structure can resist the design actions and that each element has a design capacity at least equal to the design action effects.

Strength designations (property class)

The strength of 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

- Nominal tensile strength = 4 x 100 = 400 MPa
- Nominal yield strength = 0.6 x 400 = 240 MPa

Commercial fasteners

Commercial low carbon steel bolts used in the steel industry are manufactured to AS 1111.1 which calls for a minimum tensile strength of 400 MPa, with the property class designation 4.6. Design stresses are specified in AS 4100.

M12 hot dip galvanized commercial bolts are commonly used for connections in purlin and girt applications. Cleats and lightly loaded brackets typically use M16 bolts, while M20 and M24 bolts are normally used in general structural connection and as holding down bolts. The larger sized M30 and M36 bolts are often used as anchor bolts.

Table 2: Mechanical properties of property class 4.6 bolts

Mechanical property	Nominal	Minimum
Tensile strength, f_{uf} (MPa)	400	400
Lower yield strength, R_{el} (MPa)	240	240
Stress under proof load, S_p (MPa)	225	–

Identification

Commercial bolts usually carry the maker's name and the metric M on the bolt head and may also carry the property class.

Nuts should be marked to identify the manufacturer as well as have a property class mark. Marking should be located on either the sides of the nut, or on the non-bearing face of the nut. Regular nuts and high nuts are mated with externally threaded fasteners according to their property class.

Nuts of a higher property class can replace nuts of a lower property class and it is common in Australia to use property class 5 nuts in conjunction with property class 4.6 bolts.

Hot dip galvanized flat washers have no marking requirements.

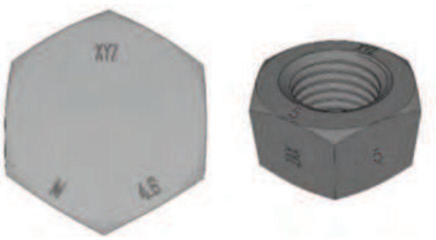


Figure 6: Marking for Commercial Bolts and Nuts

Figure 7: The Austin hospital carpark made extensive use of bolted connections for complex joints

Tower fasteners (AS 1559)

Transmission towers are designed as critically stressed structures and the very large number of tower bolts used has 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 property class 5.6 was developed to meet this need and hot dip galvanizing is the standard finish used 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. Tower bolts are commonly used in the range of M12-M30.

Nuts are property class 5, double-chamfered and tapped oversize after galvanizing to tolerance class 6AZ. All nuts are provided with a clean, and dry to the touch, lubricant coating to prevent internal thread corrosion and seizure on assembly.

Table 3: Mechanical properties of tower bolts

Mechanical property		Normal temperature application	Low temperature application
Tensile strength under wedge loading, R_m, (MPa)		480	480
Upper yield strength, R_{eH}, (MPa)		340	340
Stress under proof load S_p, (MPa)		320	320
Shear stress T, (MPa)		320	320
Charpy V-notch impact strength	Average of 3 tests	27J at 0ºC	27J at -20ºC
	Individual test	20J at 0ºC	20J at -20ºC

There are two options for washers with tower bolts: a typical flat washer and a helical spring washer. Flat washers are slightly smaller than those used in AS/NZS 1252.1 and without nibs. Spring washer designs were included in the 2018 edition of the Standard, using some of the requirements of AS 1968 (withdrawn) and are to be heat treated after coiling to a hardness of 450-540HV. AS 1559 has specific test methods for washers which differ from those in AS/NZS 1252.1

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 measures 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 are indented with the letter T for Tower or TL for low temperature tower application. The indentation is located on either the top of the head or on one of the hexagon flats. The makers name should also be indented on the head of the bolt. Bolts may have markings showing the nominal bolt length in millimetres.

Nuts should be marked to identify manufacturer as well as including the property class mark alongside the letter Z. This indicates the tolerance class of the thread. Marking should be located on either the sides of the nut or on the non-bearing face of the nut.

Hot dip galvanized flat washers have no marking requirements. To avoid a reduction in serviceability, hot dip galvanized helical spring washers are also unmarked.

Figure 8: Electrical transmission towers use large numbers of bolted connections for ease of construction and low maintenance in critical infrastructure

Figure 9: Marking For Tower Bolts And Nuts

High strength fasteners

These fasteners are commonly used in structural applications. M16 hot dip galvanized high strength structural bolts are commonly used for structural connections in small members, while M20 and M24 are commonly used in both flexible and rigid connections. M30 diameter is used less 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.

4 Benefits of using HDG high strength fasteners

1. Smaller bolts of higher strength
2. Fewer bolts and bolt holes
3. Reduced member fabrication cost
4. Faster erection and reduced erection cost

Property class 8.8

The bolt and nut material properties between AS/NZS 1252.1 and EN 14399-3 System HR are identical as both rely on ISO 898-1 (AS 4291.1 [12]) and ISO 898-2 (AS/NZS 4291.2 [13]), respectively.

Table 4: Mechanical properties of property class 8.8 high strength bolt assemblies to AS/NZS 1252.1

Mechanical property	Nominal	Minimum
Tensile strength, f_{uf} (MPa)	800	830
Stress at 0.2% non-proportional elongation, $R_{p0.2}$ (MPa)	640	660
Stress under proof load, S_p (MPa)	600	–

Hot dip 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.

The proof load requirements for hot dip galvanized nuts under the requirements of AS/NZS 1252.1 differ significantly from that shown in AS/NZS 4291.2. There are minor differences in the material hardness requirements for washers with AS/NZS 1252.1 specifying a hardness of 320-390 HV (33-41 HRC), irrespective of whether the washers have plain finish or are hot dip galvanized, while EN 14399-5 calls up hardened and tempered washers to ISO 4759-3 with a hardness range of 300 HV to 370 HV.

In high strength bolting, correct tightening is essential and AS/NZS 1252.1 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 have a higher specified hardness than uncoated nuts in accordance with Table 3.1 of AS/NZS 1252.1.

Table 5: Mechanical properties of hot dip galvanized high-strength steel nuts

Proof stress (MPa)	Vickers Hardness (HV)	
	Max.	Min.
1165	353	260

Note: The coating must be removed before hardness testing.

Table 6: Proof loads for hot dip galvanized high strength steel nuts from AS/NZS 1252.1

Thread	Tensile stress area of threaded test mandrel, A_s (mm²)	Proof load (kN)
M12	84.3	98
M16	157	182
M20	245	285
M22	303	353
M24	353	411
M27	459	534
M30	561	653
M36	817	951

Figure 10: A car park structure with typical bolted connections

Identification

Galvanized high strength bolts to AS/NZS 1252.1 property class 8.8 can be identified by three radial lines on the bolt head, with the maker's name and the property class symbol which can be located on either a side face or the top of the head.

Nuts to property class 8 for use with structural bolts can be identified by three circumferential lines on the face of the nut, the property class symbol, which is indented on an external face, and the manufacturer identification trademark on a similar face. 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.

The alternative 8.8 HR bolts do not have the radial lines, but instead have the property class and HR marked on the head of the bolt.

Nuts are marked similarly to the bolt, while washers are plain round without the nibs, but are marked with the maker's name and H symbol.

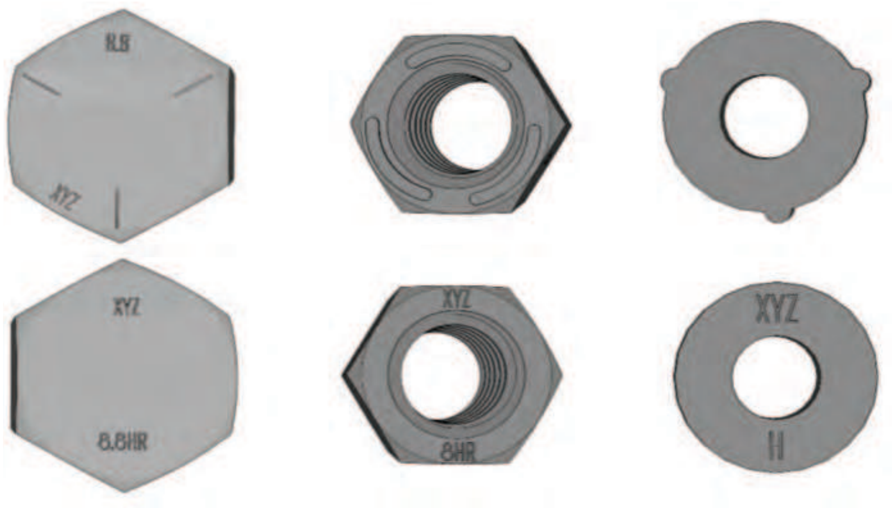


Figure 11: Marking for class 8.8 high strength bolts, nuts and washers

Property Class 10.9

High strength structural bolt assemblies for preloading that are manufactured in accordance with EN 14399-3, System HR, property class 10.9 are the only additional assembly type that is deemed to satisfy the requirements of AS/NZS 1252.1 and as such may be used where reference is made to property class 10.9 fasteners conforming to the Standard.

Currently there is limited use of higher grade 10.9 bolt assemblies in the Australian market, although the potential increase in structural capacity of connections from the use of property class 10.9 bolts instead of 8.8 bolts may see this increase over time.

High strength bolts assemblies to property class 10.9 come in sizes M12, M16, M20, M24, M30 and M36, although the most used sizes are M20 and M24.

Table 7: Mechanical properties of high strength bolt assemblies to EN 14399 system HR property class 10.9

Mechanical property	Nominal	Minimum
Tensile strength, f_{uf} (MPa)	1000	1040
Stress at 0.2% non-proportional elongation, $R_{p0.2}$ (MPa)	900	940
Stress under proof load, S_p (MPa)	830	–

Identification

Hot dip galvanized high strength bolts to AS/NZS 1252.1 property class 10.9 can be identified by the maker's name and the property class (10.9HR) which is to be located on either a side face or the top of the head.

Nuts to property class 10.9 for use with structural bolts can be identified by the property class and the maker's name or trademark on a similar face.

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 of property class 10.9 can be identified by the property class and the maker's name or trademark on a similar face and are dimensionally larger than commercial and high strength washers.

Figure 12: Marking for class 10.9 High strength bolts, nuts and washers

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:

- **Bearing-type connection:** A connection made using either snug-tight bolts, or high-strength bolts tightened to induce a specified minimum bolt tension, in which the design action is transferred by shear in the bolts and bearing on the connected parts at the strength limit state.

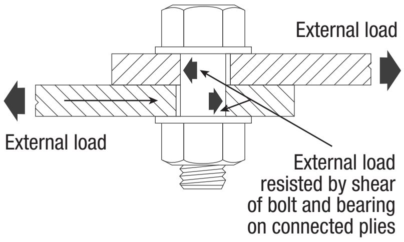


Figure 13: Bearing type connection

- **Friction-type connection:** A connection made using high-strength bolts tightened to induce a specified minimum bolt tension so that the resultant clamping action transfers the design shear forces at the serviceability limit state acting in the plane of the common contact surfaces by the friction developed between the contact surfaces.

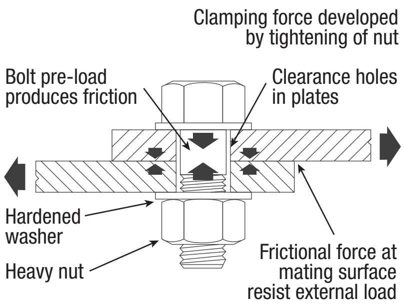


Figure 14: Friction type connection

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

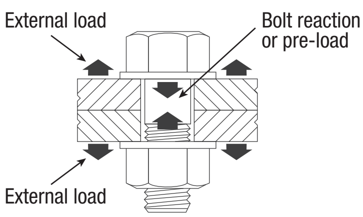


Figure 15: Axial tension mode

Bolting category system

The bolting category identification system is used to identify the property class and the bolting design procedure.

S represents snug tight, where snug tight is the tightness attained by a few impacts of an impact wrench or by the full effort of a person using a podger spanner to bring the plies into firm contact. It is the final mode of tightening for bolting categories including the designation S (e.g. 8.8/S), and the first step in full tensioning for bolting categories including the designation TF and TB (e.g. 10.9/TB).

Note: Firm contact occurs when the plies (the plates that form part of a bolted connection) are solidly seated against each other, although this does not have to be continuous contact.

High strength structural bolts in the snug tight condition can 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.

TB represents fully tensioned, bearing type joint

TF represents fully tensioned, friction type joint

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.

Table 8: Bolts and bolting category

Bolting category	Bolt Standard	Bolt type	Bolt grade	Method of tensioning
4.6/S	AS 1110 (series) and AS 1111 (series)	Commercial	4.6	Snug tight
8.8/S	AS 1110 (series) and AS/NZS 1252.1	High strength	8.8	Snug tight
8.8/TB	AS/NZS 1252.1	High strength	8.8	Full tensioning
8.8/TF	AS/NZS 1252.1	High strength	8.8	Full tensioning
10.9/S	AS/NZS 1252.1	High strength	10.9	Snug tight
10.9/TB	AS/NZS 1252.1	High strength	10.9	Full tensioning
10.9/TF	AS/NZS 1252.1	High strength	10.9	Full tensioning

Note: Bolts to AS 1110 and AS 1111 are not suitable for full tensioning.

The bolting category identification system is used to identify the property class and the bolting design procedure.

Design for high strength bolting

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

High strength fasteners in a friction-type joint (bolting category 8.8/TF or 10.9/TF) must be used where a bolted joint is designed and

- slip in the serviceability limit state is to be avoided in a connection, or
- the joint is subject to impact or vibration.

When non-slip fasteners (such as high-strength bolts in a friction-type connection or welds) are used in a connection in conjunction with slip-type fasteners (such as snug-tight bolts, or tensioned high strength bolts in bearing-type connections), all of the design actions must be assumed to be resisted by the non-slip fasteners.

Where bolts are designed to carry only tensile forces, the connection must be designed to carry any additional prying forces, which is the additional tensile force developed as a result of the flexing of a connection component in a connection subjected to tensile force.

All fasteners are required to have a washer under the rotated part to minimise damage to the surface and coating.

Bolt strength limit states

Bearing type joint design

Design capacity factors (Ø) for strength limit states of bolted connections

AS 4100 provides various capacity factors for bolted connections in bearing.

Table 9: Design capacity factors for bolted connections

Connection	Capacity factor (Ø)
Bolt in shear	0.80
Bolt in tension	0.80
Bolt subject to combined shear and tension	0.80
Ply in bracing	0.90
Bolt group	0.80

Joints subject to shear and combined shear and tension

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

Provided the 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 hot dip galvanized coatings without a change in the design values.

Joints subject to shear force only

Bearing type joints subject to only shear force must be proportioned so that the shear force (V_f^*) on any bolt does not exceed the nominal shear capacity of a bolt (V_f) multiplied by the capacity factor (Table 9).

$$V_f^* \leq øV_f$$

The nominal shear capacity is shown in Table 11 (for 4.6) and Table 12 (for 8.8) based on the following equation.

$$V_f = 0.62 f_{uf} k_{rd} k_r (n_n A_c + n_x A_o)$$

Where

f_{uf} = minimum tensile strength of the bolt as specified in the relevant Standard (Table 8)

k_{rd} = Reduction factor to account for the reduced ductility of grade 10.9 bolts when subjected to shear where threads intercept the shear plane
= 1.0 for grade 4.6 and grade 8.8 bolts
= 1.0 for grade 10.9 bolts where threads do not intercept the shear plane
= 0.83 for grade 10.9 bolts where threads intercept the shear plane

k_r = reduction factor (Table 10) to account for the length of a bolted lap connection (l_j) and for all other connections k_r equals 1.0

n_n = number of shear planes with threads intercepting the shear plane

A_c = minor diameter area of the bolt as defined in AS 1275

n_x = number of shear planes without threads intercepting the shear plane

A_o = nominal plain shank area of the bolt

Table 10: Reduction factor for a bolted lap connection

	Length of a bolted lap connection and reduction factor applied		
Length (l_j), mm	$l_j < 300$	$300 \leq l_j \leq 1300$	$l_j > 1300$
k_r	1.0	$1.075-(l_j / 4000)$	0.75

Table 11: Nominal shear capacities of commercial bolts – 4.6/S bolting category

Bolt size	Shear values (single shear)	
	Threads included in shear plane	Threads excluded from shear plane
M12	15.1	22.4
M16	28.6	39.9
M20	44.6	62.3
M24	64.3	89.7
M30	103	140
M36	151	202

Table 12: Nominal shear capacities of high strength bolts – 8.8/S, 8.8/TB, 8.8/TF bolting categories

Bolt size	Shear values (single shear)	
	Threads included in shear plane	Threads excluded from shear plane
M16	59.3	82.7
M20	92.6	129
M24	133	186
M30	214	291

For property grade 10.9 bolts the following equations are used to calculate the shear values (Table 13).

$V_{fn} = 0.62 F^{*}_{uf} A_c$

$V_{fx} = 0.62 F^{*}_{uf} A_o$

Where

F^{*}_{uf} – minimum tensile strength of a bolt (Table 8).

A_c – minor diameter of a bolt

A_o – nominal plane shank area of a bolt

Table 13: Nominal shear capacities of high strength bolts – 10.9/S, 10.9/TB, 10.9/TF bolting categories

Bolt size	A_c	A_o	Shear values (single shear)	
			Threads included in shear plane (V_{fn})	Threads excluded from shear plane (V_{fx})
M16	0.115	0.161	74.3	103
M20	0.180	0.251	116	161
M24	0.258	0.361	166	233
M30	0.416	0.565	268	364

Joints subject to tension only

Tension type joints subject to only tensile force must be proportioned so that the tensile force (N^{*}_{tf}) on any bolt does not exceed the nominal tension capacity of a bolt (N_{tf}) multiplied by the capacity factor (Table 9).

$N^{*}_{tf} \leq \phi N_{tf}$

Where:

$N_{tf} = A_s f_{uf}$

A_s = the tensile stress area of a bolt as specified in AS 1275

All fasteners are required to have a washer under the rotated part to minimise damage to the surface and coating.

Figure 16: High strength bolted connection joining multiple plies

Table 14: Nominal and design tension capacity on any bolt

Nominal diameter of bolt	Stress area, A_s (mm²)	Nominal tension capacity (N_{tf}) for bolt grade, kN			Maximum design tension capacity (N^*_{tf}) for bolt grade, kN		
		4.6	8.8	10.9	4.6	8.8	10.9
M16	157	62.8	126	157	50.2	104	131
M20	245	98.0	196	245	78.4	163	204
M24	353	141	282	353	113	234	294
M30	561	224	449	561	180	373	467
M36	817	327	654	817	261	542	680

Joints subject to shear and tension

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

$$\left(\frac{V^*_f}{\o V_f}\right)^2 + \left(\frac{N^*_{tf}}{\o N_{tf}}\right)^2 \leq 1.0$$

Friction type joint design

Joints subject to shear force only

For friction-type connections (bolting categories 8.8/TF or 10.9/TF) in which slip in the serviceability limit state is required to be limited, a bolt subjected only to a design shear force (V^*_{sf}) in the plane of the interfaces must be equal to or lower than the nominal shear capacity of a bolt (V_{sf}) multiplied by the capacity factor Ø = 0.7.

$$V^*_{sf} \leq ØV_{sf}$$

Where

$V_{sf} = \mu n_{ei} N_{ti} k_h$

μ = slip factor*

n_{ei} = number of effective interfaces.

N_{ti} = minimum bolt tension at installation (provided in Table 15.2.2.2 of AS 4100).

k_h = factor for different hole types, as specified in Clause 14.3.2 of AS 4100.

= 1.0 for standard holes.

= 0.85 for short slotted and oversize holes.

= 0.70 for long slotted holes.

*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. See *Slip factors affecting mating surfaces* for important aspects relating to slip factors on hot dip galvanized surfaces.

Maximum design shear capacities are shown in Table 15 for strength grade 8.8 bolts and Table 16 for strength grade 10.9 bolts.

Table 15: Design capacities of strength grade 8.8 bolts - Serviceability limit state

Bolt size	Bolt tension at installation, N_{ti} (kN)	Axial tension (kN)	Design capacity in shear (kN)		
			$K_h = 1$	$K_h = 0.85$	$K_h = 0.7$
M16	95	66.5	23.3	19.8	16.3
M20	145	101.5	35.5	30.2	24.9
M24	210	147	51.5	43.7	36.0
M30	335	234.5	82.1	69.8	57.5
M36	490	343	120	102	84.0

Table 16: Design capacities of strength grade 10.9 bolts - Serviceability limit state

Bolt size	Bolt tension at installation, N_{ti} (kN)	Axial tension (kN)	Design capacity in shear (kN)		
			$K_h = 1$	$K_h = 0.85$	$K_h = 0.7$
M16	130	72.1	25.2	21.4	17.7
M20	205	143.5	50.2	42.7	35.2
M24	295	206.5	72.3	61.4	50.6
M30	465	325.5	113	96.8	79.7
M36	680	476	166	141	116

Note: AS 4100 provides that the slip factor for clean as-rolled steel surfaces is to 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 in *Slip factors affecting mating surfaces*.

Figure 17: Modular construction is enabled through bolted connections

Variation in design values with bolt strength and joint design

Design values vary with joint design, bolt type and level of bolt tightening. Table 17 shows 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 (assumes slip factor = 0.35, where relevant).

Table 17: Design values in shear of M20 bolts in various strength grades

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
10.9/S	116	161
10.9/TF	50.2	50.2
10.9/TB	116	161

Design values vary with joint design, bolt type and level of bolt tightening.

Joints subject to external tension in addition to shear

Bolts in a connection for which slip in the serviceability limit state is to be limited, which are subject to a design tension force (N^*_{tf}), must satisfy:

$$\left(\frac{V^*_{sf}}{øV_{sf}}\right) + \left(\frac{N^*_{tf}}{øN_{tf}}\right) \leq 1.0$$

Where:

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

N^*_{tf} = design tensile force on the bolt.

ø = capacity factor (See Clause 3.5.5 of AS 4100).

V_{sf} = nominal shear capacity of the bolt as specified in Clause 9.3.3.1 of AS 4100.

N_{tf} = nominal tensile capacity of the bolt.

In this case, the nominal tensile capacity of the bolt (N_{tf}) is taken as:

$N_{tf} = N_{ti}$

Where:

N_{ti} is the minimum bolt tension at installation as shown in Table 15 and Table 16.

The strength limit state must also be separately assessed in accordance with Clause 9.3.2.3 of AS 4100.

Design details for bolts

Hot dip galvanized structures that are to be joined using bolted connections should always have the bolt holes formed in the structural steel prior to galvanizing. This ensures full protection from corrosion in the bolt hole and maximises the life of the structure. In some designs, the inside of bolt hole may attract extra zinc from inadequate draining of the molten zinc. This can be left 'as is', or lightly cleaned if the bolt access is restricted. The area around a bolt hole should have any lumps or runs removed to ensure adequate flatness, although this is not generally a common problem. Care should be taken with any cleaning so as not to remove too much zinc and damage the protection.

Centres

The minimum distance between the centres of fastener holes must be at least 2½ times the nominal diameter of the bolt (d_f).

The maximum distance between the centres of fastener holes must be the lesser of 200 mm or 15 x the thickness of the thinner connected ply. There are exceptions to this rule where corrosion of the steel can be avoided during the design lifetime (such as where a hot dip galvanized coating is used). In this case the maximum distance between centres can be increased to the lesser of 300 mm or 32 x the thickness of the thinner connected ply.

Edge distance

The minimum edge distance for a bolt hole from the edge of a section is related to the type of edge. For example, flame and machined cut edges require a larger edge distance than a hot rolled section edge.

- Sheared or flame cut edge: 1.75 x d_f
- Machine cut, sawn or planed edge: 1.50 x d_f
- Rolled edge of a rolled flat bar or section: 1.25 x d_f

The maximum distance from the centre of any bolt hole to the nearest edge of parts in contact with one another is 12 x the thickness of the thinnest outer ply, but not exceeding 150 mm.

Hole Design

Normal bolt holes

The nominal diameter of a bolt hole (excluding bolt holes in base plates) is:

- For $d_t \leq 24$ mm: 2 mm larger than d_f
- For $d_t > 24$ mm: 3 mm larger than d_f

For base plates, the hole diameter is ≤ 6 mm larger than d_f. If the hole diameter is ≥ 3 mm more than d_f, a plate washer with a thickness ≥ 4 mm shall be used under the nut and the washer must be sized so that the distance from the edge of the hole to the edge of the washer is at least half the hole diameter.

Oversized bolt holes

Oversized holes are sometimes required for fabrication and erection purposes.

Oversized holes must have hardened washers or plate washers installed under both the bolt head and nut. The washer must be sized so that the distance from the edge of the hole to the edge of the washer is at least half the hole diameter.

Oversized holes must not be larger than the largest of 1.25 x d_f or d_f + 8 mm.

Slotted bolt holes

Slotted holes are described as either short or long slotted holes and, like oversize holes, are sometimes required for fabrication and erection purposes. Slotted holes should not be made except when noted on the specification.

Short slotted holes can be used on both friction-type and bearing-type connections (and in all or any of the plies). This type of bolt hole has certain restrictions in use for bearing-type connections subject to shear force. In this case they can only be used when the connection is not eccentrically loaded and the bolt can bear uniformly, and where the slot is normal to the direction of the design action.

Short slotted holes must have hardened washers or plate washers installed under both the bolt head and nut. The washer must be sized so that the distance from the edge of the hole to the edge of the washer is at least half the hole diameter.

The holes must not be wider than the allowances above for holes in general and must be no longer than the larger of 1.33 x d_f or d_f + 10 mm.

Long slotted holes can be used on both friction-type and bearing-type connections although they have tighter restrictions for use than short slotted holes and can only be used in alternate plies. In bearing-type connections subject to shear force they can only be used when the connection is not eccentrically loaded and the bolt can bear uniformly, and where the slot is normal to the direction of the design action.

A plate washer ≥ 8 mm thick must be installed under both the bolt head and nut and the washer must completely cover the hole and be sized so that the distance from the edge of the hole to the edge of the washer is at least half the hole diameter.

Hot dip galvanized structures that are to be joined using bolted connections should always have the bolt holes formed in the structural steel prior to galvanizing.

Tightening procedures for high strength structural bolts

The installation and tightening of a high strength structural fastener set is at least as costly as the fastener set itself, and the selection of bolt type and bolt tightening procedure is an important consideration in the economics of high strength bolted structures. AS/NZS 5131 specifies that all material within the grip of the fastener must be steel and compressible material is not included, except for load indicating washers. The length of a bolt must be such that at least one clear thread shows above the nut and at least one thread plus the thread run out is clear beneath the nut after snug tightening.

Nuts

Nuts must be installed so that identification marking is visible for inspection after installation. For fasteners where the assembly is subject to impact or significant vibration the construction specification should specify the method required to secure the nuts (in addition to normal tightening procedures). Clause 5.5.8 of AS/NZS 5131 provides more information on locking devices. Assemblies subject to tension only do not require any additional locking devices.

Washers

For hot dip galvanized surfaces, a washer must be provided under the part of the fastener set (nut or bolt head) that is rotated during the tightening process. The construction specification may specify for a washer to be placed under both the nut and the bolt head where it is deemed necessary.

Where oversized or slotted holes are used, plate washers are required (see *Hole Design*). These plate washers must have similar mechanical properties to other components of the connection and all components must have compatible coatings with similar corrosion resistance.

Snug tightening of bolts

All bolt holes must be aligned to permit insertion of the bolts without damage to the thread. Drifting to align holes must be carried out in a manner that does not distort the steel or enlarge the holes.

Re-use of bolts used in snug tightening is permitted so long as the bolt and the thread are undamaged and the nuts run freely in accordance with Clause 8.2.3 of AS/NZS 5131.

Snug tight definition

Snug tight condition is achieved when the connection is tightened with a few impacts of an impact wrench or by the full effort by competent personnel using a standard podger spanner to bring the plies into firm contact. Podger spanners are graded in length in relation to bolt size and strength. For example, a 450mm long spanner would be used for M20 high strength structural bolts, and a 600mm long spanner for M24 high strength structural bolts.

Snug tightening is applied in the following situations:

1. **Category 4.6/S:** The final level of bolt tightening in general structural bolting using commercial bolts.
2. **Category 8.8/S and 10.9/S:** The final level of bolt tightening using high strength structural bolts. 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. **Category 8.8/TF, 8.8/TB, 10.9/TF, and 10.9/TB:** An intermediate level of bolt tension applied as the first stage in full tightening.

The growing popularity of high strength structural bolts to AS/NZS 1252.1 used in a snug tight condition leads to the situation where bolts may require further tightening to AS/NZS 5131 in one application and only snug tightening in another. To prevent confusion and ensure correct tightening, the designer must show 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.

Figure 18: HDG bolted connections used to support a façade

Figure 19: The Scenic railway in the Blue Mountains in NSW showing the use of HDG bolts in railway sleeper and stair connections

Tensioning of high strength bolts

For joints designed in accordance with AS 4100, either as 8.8/TF and 10.9/TF friction type joints or 8.8/TB and 10.9/TB bearing type joints, all bolts must first be tightened to the snug tight condition. All bolts in a completed connection are to be tightened to at least the minimum bolt tension (Table 18) defined as the stress under proof load (S_p) x stress area (A_s) as required in AS 4100 and AS/NZS 5131. This can be achieved using either the part-turn method of tensioning or using a direct-tension indication device.

High strength bolts that are to be tensioned can be used temporarily during erection to facilitate assembly of a connection. These bolts should not be fully tensioned until all the bolts in the connection have first been tightened to the snug tight condition.

Table 18: Minimum bolt tension after tightening for high strength bolts

Nominal diameter of bolt	Minimum bolt tension (kN)	
	8.8	10.9
M16	95	130
M20	145	205
M24	210	295
M30	335	465
M36	490	680

Torque control tightening of galvanized bolts and nuts is not explicitly prohibited in the Standards; however it has not been widely used in Australia because of the variable torque and induced tension relationship of zinc coatings, even when lubricant coated (see *Torque and induced tension relationship in tightening* for a historical research). The ASI says (14) that:

> Using a torque wrench to tighten bolts to a defined tension is accepted practice in both Europe and America. However, this approach does require a known and reproducible relationship between torque applied to the bolt and the resulting tension, which can be significantly affected by bolt properties such as thread engagement and coating. Historically, in the Australian marketplace and in particular with regard to both our significant adoption of galvanized bolts and issues with compliant supply, there has not been the confidence with torque-controlled methods of tightening.
>
> There is an expectation that with the revision to AS/NZS 1252, including significant focus on ensuring compliant supply, the market will respond positively, and we will get improved compliance and bolt assembly performance. This then opens the door to confidence that we will be able to procure bolt assemblies with a reliable torque-tension relationship.

Part turn tightening

Part turn tightening is to be completed after snug-tightening. Location marks are made in order to mark the position of the bolt and nut in relation to each other in order to be able to control the amount of final nut rotation. These marks can then be used for final tightening and inspection. Taper washers are required if the surface slope exceeds 3° and flat washers must be used under the rotating component.

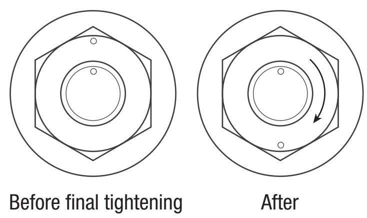


Figure 20: Part turn tightening showing location marks in the before and after positions

Rotate the nut by the given amount in Table 19 and whilst completing the final tensioning the component not turned by the wrench must not rotate. Where it is impractical to turn the nut due to access or other reasons the bolt may be rotated so long as there is a washer under the bolt head and any rotation of the nut is prevented.

Table 19: Nut rotation from the snug tight position

Bolt length	Disposition of outer face of bolted parts (see Notes 1-4)		
(underside of bolt head to the end of the 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	⅓ turn	½ turn	⅔ turn
Over 4 diameters but not exceeding 8 diameters	½ turn	⅔ turn	⅚ turn
Over 8 diameters but not exceeding 12 diameters (see Note 5)	⅔ turn	⅚ turn	1 turn

Notes:

1. Tolerance on rotation: for ½ turn or less, 1⁄12 of a turn (30º) over and nil under tolerance; for ⅔ turn or more, ⅛ of a turn (45º) over and nil under tolerance.
2. The bolt tension achieved with the required amount of nut rotation will be at least equal to the minimum bolt tension (Table 18).
3. Nut rotation is the rotation relative to bolt, regardless of the component turned.
4. The 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 solidify fitted steel. The 'assembly test' specified in AS/NZS 1252.1 is a suitable test.

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 requirements for use are

1. The device must show it is suitable for the application by testing a representative sample of at least three bolts for each diameter and bolt length combination and for each grade of bolt that will be used. The bolt assemblies used for testing must be taken from the same assembly group being used for the project. The test must be carried out by a calibration device that indicates the bolt tension. The calibration test must demonstrate a tension of at least 1.05 times the minimum bolt tension given in Table 18.
2. All bolts must be snug tightened prior to using the direct tension indicator.
3. The bolts must then be tensioned to the minimum bolt tensions specified in Table 18. These values should be indicated by the direct tension indication device. Tensioning should only be carried out by competent personnel and adhere with the tension indication device manufacturer's specification.

Tightening procedure with load indicator washers

The most used direct tension indicating device in Australia is the load indicator washer. The load indicator washer is similar in size to a normal circular washer, with four to seven protrusions depending on size, on one face of the washer (Figure 21). The washer is assembled under the bolt head so that the protrusions bear on the underside of the head (Figure 21). 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. If over compression does occur, the whole assembly including the compression washer must be removed and replaced with a new assembly and new compression washer.

In applications where it is necessary to rotate the bolt head rather than the nut, the load indicator can be fitted under the 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.

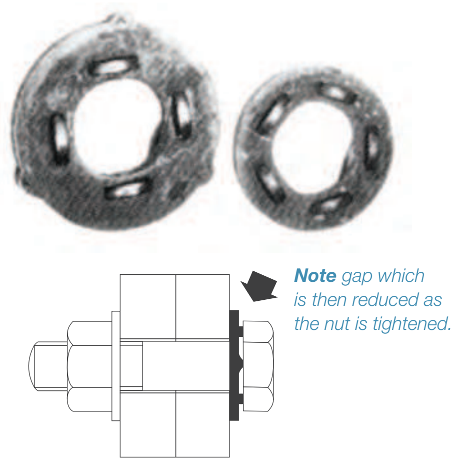


Figure 21: Load indicating washers fitted under bolt head

Assembly testing and minimum nut rotation

Assembly testing for fasteners are a requirement of AS/NZS 1252.1. The test verifies the suitability of high strength bolt, nut, and washer assemblies for tensioning in steelwork construction.

Inspection of fasteners

Fasteners purchased for use in fabrications covered under AS/NZS 5131 must be subject to an inspection and test plan (ITP).

The ITP must identify the bolted connection to be inspected, who is to carry out the inspections, the stages at which the inspection is to be carried out and the method and extent of the inspection to be used. Any special requirements of the inspection should be identified in the construction specification.

Inspection after snug tightening

All connections which are initially snug tightened are inspected after snug tightening with the structure aligned locally, for the following:

1. Correct position and angle for all the bolts in the connection.
2. Ensuring all the assemblies are of the right grade and size.
3. Bolts which have insufficient or excessive thread beyond the nut.
4. Ensuring locking nuts are in the joints where they have been required and prescribed.
5. All plies are the correct thickness and dimensions.

All snug tight connections are inspected to ensure they have been properly packed and that all plies of the connection have been brought into firm contact. All bolts in the joint are checked for enough tightening to ensure they will not turn without the use of a spanner.

Fasteners purchased for use in fabrications covered under AS/NZS 5131 must be subject to an inspection and test plan.

Inspection of tensioned high strength bolted connections

The connection must first have already been inspected at the snug tight stage before inspection after tensioning. For friction type connections, the surfaces are visually inspected prior to assembly. Assembly of that connection must not start until the surface condition meets the requirements in the construction specification and Clause 8.4.2 of AS/NZS 5131.

The tensioning procedure must be observed over the entire process to ascertain the correct procedure and outcomes are obtained.

For construction categories CC2, CC3 and CC4 of AS/NZS 5131 the connection must be inspected after tensioning as follows:

a) Part turn tensioning – The correct part-turn (Table 19), from the initial snug tight position must be measured.
b) Direct tension indication device – The direct tension indication device must indicate the developed minimal tension, which must exceed the value given in Table 18.

Notes:

1. The manufacturer's inspection procedures should be followed when the direct tension indication device is used.
2. The use of a torque wrench for inspection is considered suitable only to detect gross under-tensioning.

If the high strength bolts have not been tensioned to the provisions in the paragraphs above, the bolts are to be either re-tensioned or new bolts installed and tensioned to the requirements given. They must then be re-inspected.

During the inspection of the direct tension indication devices they should be checked to identify any indicators where the protrusions have been fully compressed. No more than 10% of the direct tension indicators can exhibit full compression of the protrusions.

Selection of zinc coatings for bolts

There are four common processes for zinc coating of bolts. These are hot dip galvanizing, electroplating, sherardising, and mechanical plating. The zinc coating process selected is decided primarily by the duration of protection desired which should ideally be like the life of the protective coating selected for the structure itself. With thicker and more durable zinc coatings, such as created with the hot dip galvanizing process, allowances in the thread dimensions must be made to accommodate for the additional thickness of the coating.

Hot dip galvanizing

The hot dip 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 base steel and consists of a succession of zinc-iron alloy layers and an outer zinc layer.

Due to their small relative size, threaded fasteners, nuts, and washers are usually hot dip galvanized via the centrifuge process. Like other moving parts, each part needs to be galvanized separately.

Australian Standard AS/NZS 1214 *Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series)* provides for a standard minimum coating thickness regardless of fastener dimensions. This Standard, revised in 2016, is a modified adoption of the International Standard ISO 10684, *Fasteners — Hot dip galvanized coatings,* and includes the option to also galvanize washers. The revision to AS/NZS 1214 was aligned with the release of the new structural bolt Standard, AS/NZS 1252.1, *High-strength steel fastener assemblies for structural engineering - Bolts, nuts and washers, Part 1: Technical requirements*.

The HDG process develops a coating with a minimum average thickness of 50µm on threads, as defined in AS/NZS 1214. This Standard also provides information on the recommended maximum coating thickness to avoid galling. It is required under AS/NZS 1252.1 for nuts to be galvanized blank and the threaded portion cut after galvanizing. In this case the galvanized coating on the thread of the stud or bolt will provide corrosion protection for the uncoated internal thread of the nut.

All galvanized nuts must be provided with a lubricant that is clean and dry to the touch to prevent seizure on assembly. This lubricant should also act to prevent corrosion on the ungalvanized internal thread prior to assembly. It is not necessary to also lubricate the galvanized bolts.

Economics of hot dip galvanized coatings on bolts

Corrosion protection on bolts should preferably match the rest of the structure and in most circumstances, economics favours the use of galvanized bolts rather than painting after erection (15). Where the durability of the galvanized bolts is lower than the rest of the structure, inspection and replacement may be a more economical solution than maintenance by painting. Due to their significantly lower coating thickness, electroplated bolts do not generally provide significant exterior durability and are therefore not recommended for external applications.

Use of galvanized bolts, nuts and washers will be effective in providing all-round protection that will generally withstand erection procedures. If bolts are painted prior to installation, the paint will be damaged during tightening and the corrosion protection compromised. Bolts, nuts, and washers can also be further protected using LDPE caps designed and engineered to fit snugly over the fixings.

Table 20: Indicative cost-in-place relationships for unpainted, painted, and galvanized M20 bolts in structural applications (15)

Bolt strength grade and bolting procedure	Cost-in place		
	Unpainted	Painted	Hot dip galvanized
4.6/S	100	190	110
8.8/S	120	210	140
8.8/T	170	260	190

Durability of HDG Bolts

The life to first maintenance of HDG bolts in Australia can be estimated from AS/NZS 2312.2 (16) which in turn uses the information supplied in AS 4312 (17). The corrosivity category can be determined from local site data, the performance of existing structures over time, or by consulting a durability expert. The GAA provides a free online durability estimator to assist with the initial assessment and a guide to the service life of HDG coatings (18). The estimated range for the years to first maintenance (Table 21) is based on the minimum coating thickness required to be achieved in AS/NZS 1214. Thicker coatings are often achieved in practice and the estimates shown below are usually conservative.

Table 21: Nominal minimum life to first maintenance for HDG bolts

Durability of galvanized coating in various atmospheric conditions (years)						
Corrosivity category	C1	C2	C3	C4	C5	CX
Typical location	Dry indoors	Arid or urban inland	Coastal	Calm seashore	Surf seashore	Severe surf seashore
Life to first maintenance of coating	>100	71 – > 100	24 – 71	12 – 24	6 – 12	2 – 6

Figure 22: HDG connections can often provide a longer life to first maintenance than painted structures

Oversize tapping allowances for hot dip galvanized nuts

To accommodate the relatively thick galvanized coating on external threads and to avoid the issue of galling during tightening, galvanized bolts are manufactured to standard thread dimensions and nuts are tapped oversize after galvanizing. AS/NZS 1252.1 uses AZ/g tolerances for structural bolts (Table 22) and all fasteners galvanized to AS/NZS 1214 will be suitable.

For bolts with a galvanized coating, the increase in the effective diameter due to the galvanized coating is 4 times the coating thickness so the minimum clearance between bolt and nut thread must be at least four times the coating thickness of the bolt thread (Figure 23). This is shown as a recommended maximum coating thickness in Table 22, although this only needs to be considered if a thicker coating than the Standard is desired and able to be supplied by the galvanizer.

Table 22: Fundamental deviations and upper limits of coating thicknesses for assemblies with nuts tapped oversize

Pitch *P* (mm)	Nominal thread diameter *d* (mm)	Fundamental deviation and minimum clearance for AZ/g tolerances (µm)			Recommended maximum coating thickness (µm)
		Nut thread AZ	Bolt thread g	Minimum clearance	
1.75	12	+335	-34	369	92
2.0	16	+340	-38	378	95
2.5	20 (22)	+350	-42	392	98
3.0	24 (27)	+360	-48	408	102
3.5	30	+370	-53	423	106
4.0	36	+380	-60	440	110

Notes:

1. The numbers in parentheses are non-preferred sizes.
2. The nominal minimum average coating thickness required to comply with the requirements of AS/NZS 1214 is 50 µm.
3. Sizes listed are those in AS/NZS 1252.1. Other sizes are shown in AS/NZS 1214.
4. AS/NZS 1214 provides guidance on recommended maximum coating thicknesses for nominal sizes from M8 to M64 inclusive based on the extremes of the AZ/g tolerances.

The relationship between the coating thickness and the increase in effective diameter of an external thread (Figure 23) is shown by the triangle ABC were AB is the coating thickness, t, and BC is half the increase in the effective diameter. The effective diameter of an internal thread will be reduced by the same amount.

$$2BC = \frac{2t}{\sin\frac{60^\circ}{2}} = 4t$$

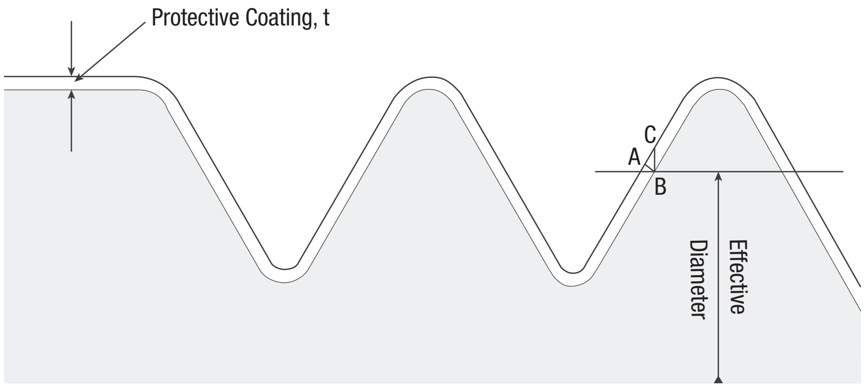


Figure 23: Thread clearance calculation when hot dip galvanizing bolts

Hydrogen embrittlement

Hydrogen embrittlement affects steels of high tensile strength (typically well more than 1000 MPa). Hydrogen embrittlement is caused by the presence of hydrogen atoms within the steel, causing normally ductile steel to become brittle. Hydrogen can be absorbed into steel during acid pickling but is expelled rapidly at galvanizing temperatures and is not a problem with lower strength components.

Grade 8.8 and 10.9 bolts are commonly hot dip galvanized and have been shown to be unaffected by the galvanizing process, however some manufacturers will recommend grade 10.9 bolts are blasted approximately 24 hours prior to galvanizing and flash pickled only to clean the steel of any remaining contaminants.

The galvanizing process has no effect on any of the grades of bolts discussed in this guide. It is best practice to consult the galvanizer prior to specifying high strength grades other than those permitted in AS/NZS 1252.1.

Zinc electroplating

Zinc electroplating 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 electroplating, although certain specialised roofing fasteners are provided with zinc plated coatings up to 35 µm to 40 µm thick. Where heavy coatings are required, galvanizing is usually a more economical alternative.

Zinc plated bolts having a tensile strength above 1000 MPa must be baked for the relief of hydrogen embrittlement and more on this subject can be found in *Fundamentals of Hydrogen Embrittlement in Steel Fasteners* [(19)].

The threads on electroplated nuts must meet tolerance class 6H in accordance with AS 1897 [(20)] after coating. Electroplated nuts conforming to AS/NZS 1252.1 must be supplied with a lubricant coating which is clean and dry to the touch to provide for satisfactory assembly.

The galvanizing process has no effect on any of the grades of bolts discussed in this guide.

Sherardising

Sherardising produces a matte 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 process is best characterised by its ability to produce a very uniform coating on small articles and avoids hydrogen embrittlement. It provides a good solution for fine threaded fasteners although these are not commonly used in structural applications.

The thickness of sherardised coatings is generally about 20 µm but can vary depending on cycle time up to about 80 µm. Sherardised coatings usually fall between zinc plated and galvanized coatings in thickness and life. The cost of sherardised bolts is usually more than galvanized bolts and thicker coatings require a longer time in the process, hence the cost of production is more than the normal sherardised bolts.

AS/NZS 1252.1 does not offer instruction on the tolerances for sherardised bolts and nuts and the user will need to decide whether the nut thread is formed before or after sherardising, however they must be supplied with a supplementary lubricant coating which is clean and dry to the touch to provide for satisfactory assembly.

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 are not susceptible to embrittlement and need not be baked after coating.

The mechanical plating process often results in zinc wastes contaminated with processing fluids that are difficult or impossible to economically recycle and for this reason the process is considered less sustainable than galvanizing.

AS/NZS 1252.1 does not offer instruction on the tolerances for mechanically plated bolts and nuts and the user will need to decide whether the nut thread is formed before or after plating, however mechanically plated nuts must be supplied with a supplementary lubricant coating which is clean and dry to the touch to provide for satisfactory assembly.

Influence of the hot dip galvanized coating on design

The presence of coatings on high strength bolts, and any coatings on structural members will need to be considered in the design phase. The characteristics of any bolt system that should be considered in design include the slip factor of the mating surfaces, the fatigue behaviour of the joint, any bolt relaxation, the effect of the coating on the nut stripping strength, and the torque/induced tension relationship in bolt tightening.

Slip factors affecting mating surfaces

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.

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 dependent on the clamping force applied by the bolts and the slip factor of the mating surfaces.

Sweep, whip, or flash blasting

Sweep, whip, or flash blasting are terms for a common technique for roughening a hot dip galvanized surface.

The aim is to expose the zinc iron alloy layer on the structural steel surface in the area of the connection without removing too much zinc.

This can be done after galvanizing by following the techniques described in AS/NZS 2312.2 Clause 7.5.3.2, AS/NZS 4680 Appendix I, or SSPC-SP 16 [21].

- Blast pressure 275 kPa (40 psi)
- Abrasive Grade 0.2 – 0.5 mm (clean garnet)
- Angle of blasting to surface no greater than 45°
- Distance from surface 350 – 400 mm
- Nozzle orifice diameter 10 – 13 mm of venturi type

Slip factors of galvanized coatings

Australian Standard AS 4100, *Steel structures*, assumes a slip factor of 0.35 for clean as-rolled steel surfaces with tight mill scale and a surface free from oil, paint, marking inks and other applied finishes. It allows the use of hot dip galvanized surfaces in friction type joints and requires the slip factor used in design calculations be based on test evidence in accordance with the procedures specified in Appendix J of the Standard. When using the test procedures in AS 4100, tests on at least three specimens are required, but five is preferred as the practical minimum. Research conducted at the University of Newcastle [22] showed that galvanized steel that has been blasted in the bolt locations prior to galvanizing to expose the zinc-iron alloy layer will achieve a slip factor of at least 0.35. Further, the follow-up research showed the slip factor was dependent on the coating structure rather than the way the coating was produced [23].

In recent years, the Australian research on galvanized surfaces has been repeated and expanded in Europe [24] and the USA [25]. This has confirmed the Australian work and resulted in changes to several international Standards and specifications for design of bolted connections. The new standardised slip factors are consistent with the University of Newcastle research results and EN 1090-2 [26] now assumes a slip factor for sweep blasted hot dip galvanized surfaces of 0.35. A higher slip factor value of 0.4 is available for surfaces that have a layer of inorganic zinc silicate applied after blasting. These changes should allow engineers to assume slip factors in design and remove the extra cost of testing.

There are minor differences in slip factor calculations between Europe and Australia and the slip factors shown in Table 23 (Europe) should be checked for compatibility. Appendix 1: Comparison of Australian & European methods for calculation of slip factors provides a comparison which shows the European data for hot dip galvanized surfaces that are sweep blasted should be able to be used in the Australian context without modification and deliver a slip factor of 0.35.

European Research

Work by Prof. Dr.-Ing. Natalie Stranghöner and others for the EU SIROCO Project [27] [28] using the test methods in EN 1090-2 Appendix G, shows that the slip factors of galvanized and non-galvanized surfaces can be substantially improved by controlled blasting. The blasting of galvanized surfaces must be performed in a manner that provides the required roughening to expose the alloy layers of the galvanized coating although care must be taken to ensure that excessive coating is not removed.

The EU SIROCO Project provided recommendations for the surface treatment that may be assumed to provide the minimum slip factor according to the specified class of friction surface (Table 23).

Note: the European research did not address the slip factor of 'as rolled' surfaces and the slip factor is shown as 0.2 for these surfaces which differs from the Australian assumption of 0.35. Simple blasting of as rolled steel can deliver slip factors in excess of the Australian slip factors by using the European methods.

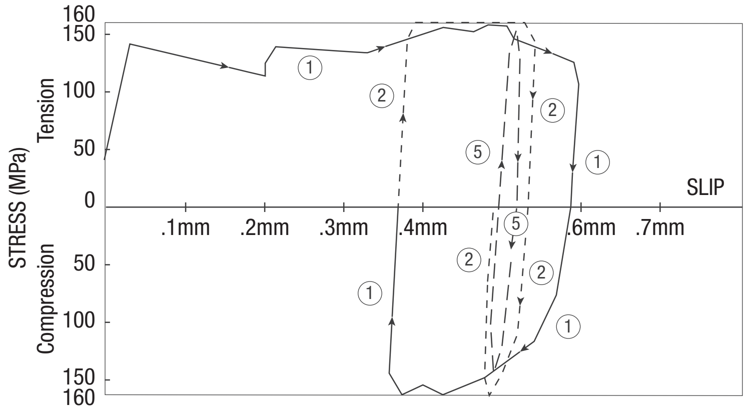
Table 23: Slip coefficient values from EU SIROCO Project

Surface treatment	Class	Slip factor (μ)
Surfaces blasted with shot or grit with loose rust removed, not pitted	A	0.5
Surfaces hot dip galvanized to ISO 1461 and flash (sweep) blasted and with alkali-zinc silicate paint with a nominal thickness of 40 μm to 80 μm	B	0.4
Surfaces blasted with shot or grit: a. Coated with alkali-zinc silicate paint with a nominal thickness of 40μm to 80μm b. Thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80μm	B	0.4
Surfaces hot dip galvanized to ISO 1461 and flash (sweep) blasted	C	0.35
Surfaces cleaned by wire brushing or flame cleaning, with loose rust removed	C	0.3
Surfaces as rolled	D	0.2

Notes:

1. ISO 1461 is equivalent to AS/NZS 4680 [29]
2. Alkali-zinc silicate paint is commonly described in Australia as inorganic zinc silicate (IZS)

Both the European and US research has shown wire brushing of the galvanized surfaces does not significantly increase slip properties with the European research only recommending sweep (whip) blasting to increase the slip factor.



Stress versus slip for fatigue specimen subjected to alternating stress of 160 MPa Galvanized members and bolts. First, second and fifth stress cycles.

Figure 24: Cyclic stress v slip for fatigue samples with hot dip galvanized plates and bolts

Fatigue behaviour of bolted galvanized joints

While a hot dip galvanized coating behaves initially as a lubricant, it has been shown in fatigue tests carried out by Professor WH Munse [30] that after the first few cycles galvanized mating surfaces tend to 'lock up', and further slip under alternating stress is negligible (Figure 24). He found that the amount of slip rapidly decreases from first to second, and then the fifth stress cycle. Munse noted further indications of 'lock up' behaviour when the joints were disassembled and observed galling of the galvanized coating 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 or the slip factor of the galvanized coating may be improved by sweep blasting.

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 has flowed under high clamping pressure, it could allow loss of bolt extension and hence tension. This factor was also studied by Munse and re-affirmed in later studies by Heistermann of Lulea University of Technology [31]. Munse found a loss of bolt load of 6.5 percent for galvanized plates and bolts due to relaxation, compared to a 2.5 percent loss for uncoated bolts and members. This loss of bolt load occurred in 5 days and little further loss was recorded. This loss can be allowed for in design and is readily accommodated.

Research in Europe and the USA is continuing on this subject.

Torque and induced tension relationship 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 on threads both increase friction between the bolt and nut threads and make the torque/induced tension relationship much more variable.

The effect of lubricants on galvanized 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 (Figure 25).

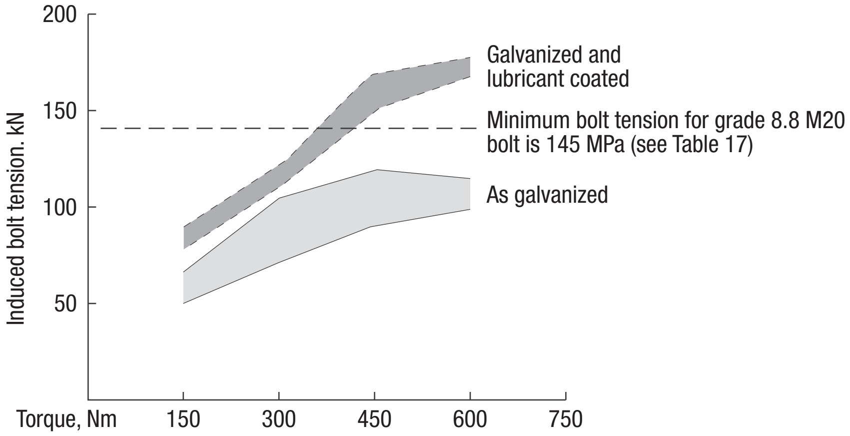
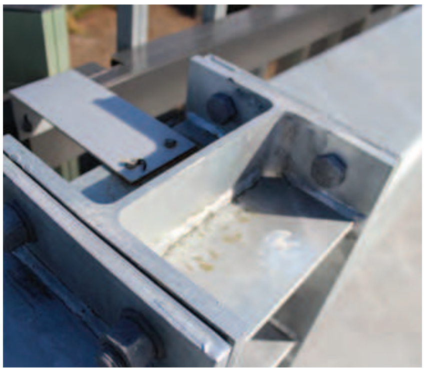


Figure 25: Torque/induced tension-relationship for M20 high strength structural bolts, galvanized and lubricant coated, and as-galvanized

Figure 25 shows the torque/induced bolt tension relationship for galvanized, and lubricant coated galvanized grade 8.8 M20 high strength structural bolts. With as-galvanized fastener assemblies, there is a wide scatter in induced tension at any one torque level, and torque cannot be used to provide a reliable method for gauging the required minimum bolt tension, as specified in AS 4100, before bolt fracture occurs. Bolt failures in torsion could result from the high friction between the as-galvanized bolt and nut threads. Accordingly, prior editions of AS 4100 did not recognise use of the torque control method for tensioning galvanized or zinc plated bolts, and the current edition prefers the part-turn tightening or direct tension indicator tightening methods.



Inspection of galvanized coating to AS/NZS 1214

The inspection of the galvanized coating may be carried out by the galvanizer, the purchaser or a third party. The inspector's duty is to observe, test and report against the contract specification and Standards. The level of inspection required must be clear and the inspector must be qualified to complete all tasks required.

To determine whether a hot dip galvanized coating meets specification and service requirements, there are two key aspects of each inspection: the coating thickness and a visual inspection for defects.

For the coating thickness requirements (Table 24), AS/NZS 1214 has relatively simple inspection methods. Measurements for the coating thickness are to be taken from every production lot, and the sample size used is as defined in the specific fastener Standard or in the customer specification.

A mean of 5 readings (minimum) taken on one fastener constitutes the local coating thickness, with the mean of all sample readings from the lot constituting the average coating thickness. If the fastener shape or size prevents 5 readings on a single fastener, then readings are to be taken on 5 separate sample items from the same lot and then averaged for one local coating thickness. ISO 1461 [32] provides information on the selection of a suitable sample size. In the case of hot dip galvanized fasteners where many parts are made in a single lot, it is common that a statistical method of inspection of the coating thickness be employed. This is especially important with hot dip galvanized washers, where the large flat surfaces encourage sticking and an acceptable rejection rate will need to be determined prior to order acceptance.

The inspection of the galvanized coating may be carried out by the galvanizer, the purchaser or a third party.

Table 24: Coating thickness requirements for ISO metric coarse thread fasteners

Article	Local coating thickness minimum, µm	Average coating thickness minimum µm
M8 to M64 inclusive	40	50

Locations for the measurement of the local coating thickness for bolts and nuts is a shown in Figure 26 and must not include the threaded portion.

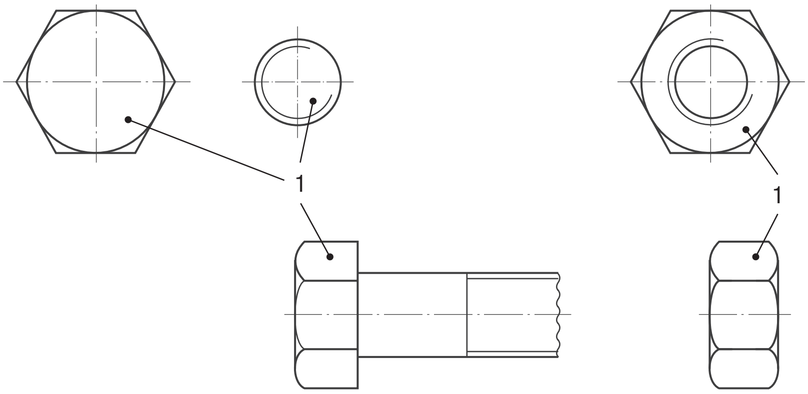


Figure 26: Allowable measuring location for fasteners to AS/NZS 1214

Appendix 1: Comparison of Australian & European methods for calculation of slip factors

SIROCO investigated the slip-resistant behaviour of carbon and stainless steel preloaded connections as well as the preloading behaviour of stainless steel bolting assemblies in principle.

The slip factor test procedure in Annex G of EN 1090-2 was investigated regarding the influence of the test speed, preload level, tightening method, criteria for the slip load and load level for extended creep tests, different bolting assemblies and surface conditions (grit blasted, hot-dip galvanized, alkali/ethyl zinc silicate coating, thermally sprayed with aluminium/zinc and combinations). Improvements regarding the slip factor test procedure have been formulated which have already partly been implemented in the revision of EN 1090-2. Enhanced slip factors allow more economic slip-resistant connections.

Aspects of concern to the report's authors included the significant variation in the literature for recognised slip factors covering nearly identical test methods. These are described in Figure 27 by Stranghöner (with the addition of AS 4100 references by the GAA). SIROCO were able to modify the previous EN 1090-2 testing methods based on their testing regime and have proposed further modifications for a future revision.

The GAA assessed the SIROCO method against that described in AS 4100 and the differences are minor. Indeed, there is a strong argument that AS 4100 should be modified to match the EN 1090-2 method, given the detailed investigation and reporting undertaken by SIROCO.

Enhanced slip factors allow more economic slip-resistant connections.

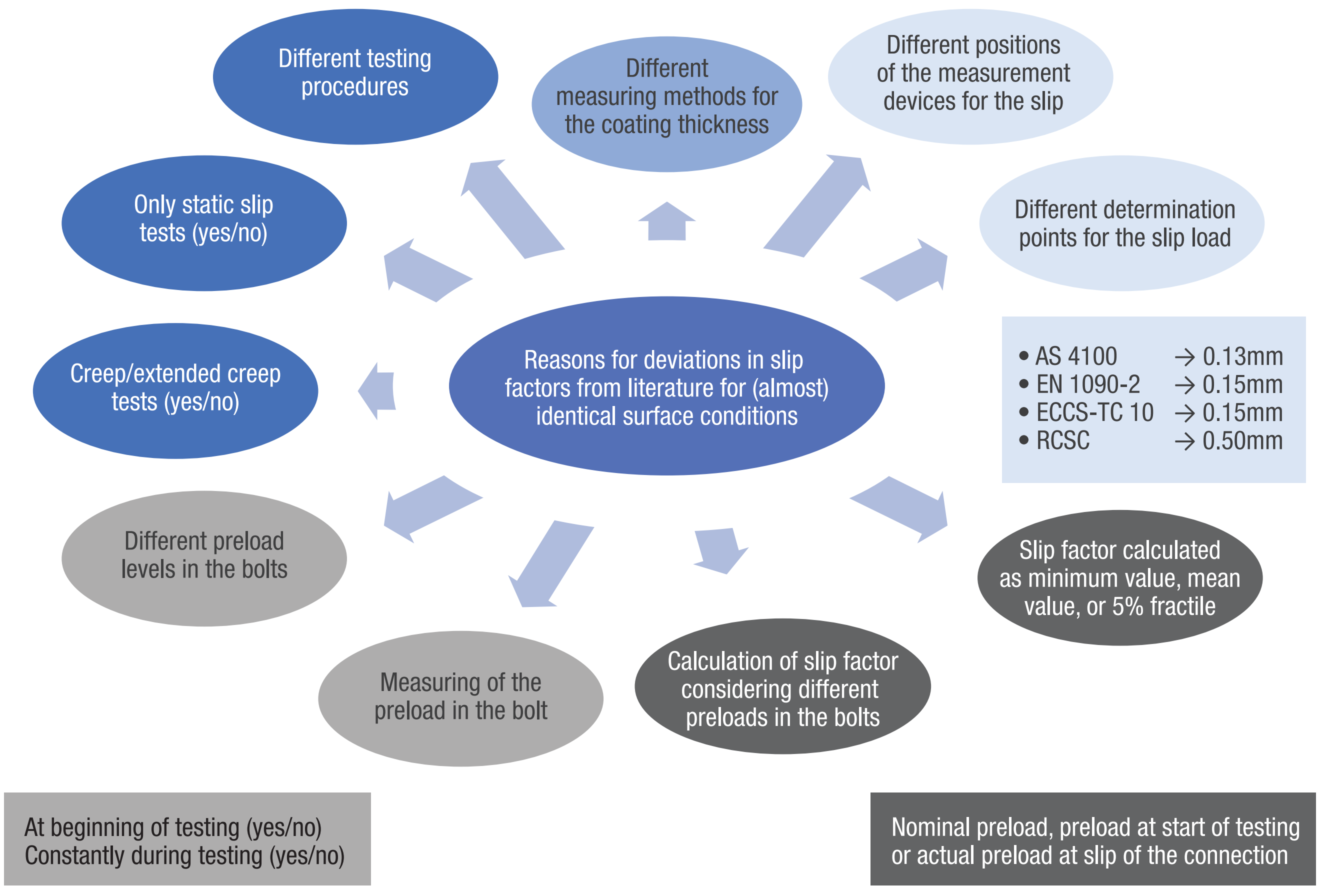


Figure 27: Reasons for deviations in slip factors from literature for almost identical surface conditions

AS 4100 Method

AS 4100 uses 2 M20 bolts in a plane with a typical test specimen length of 200 mm. The slip load is measured when a slip of 0.13 mm occurs. The test method is fully prescribed and may benefit from updating to current terminology. Full details are available in Appendix J of AS 4100.

The slip factor for design is

$\boldsymbol{\mu = k(\mu_m - 1.64\delta)}$

- k is either 0.85 when 3 specimens are tested or 0.90 when 5 or more specimens are tested
- μ_m is the mean value of the slip factor for all tests:

$$\mu_m = \frac{1}{2n}\left(\sum_{i=1}^{2n} \mu_i\right)$$

$$\mu_i = \frac{1}{2}\left(\frac{V_{si}}{N_{ti}}\right)$$

- n is the number of specimens tested (and each provides two estimates of μ_i)
- V_{si} is each measured slip load
- N_{ti} is the tension induced in each bolt
- δ is the standard deviation of the slip factor for all tests:

$$\delta = \sqrt{\left[\frac{1}{2n-1}\sum_{i=1}^{2n}(\mu_i - \mu_m)^2\right]}$$

EN 1090-2 Method

EN 1090-2 uses 4 M20 bolts in a plane with a typical test specimen length of 290 mm. The slip load is measured when a slip of 0.15 mm occurs. The method is like AS 4100 but is less prescribed. The characteristic value of the slip factor, $\mu_{5\%}$, is derived in this method and this is used as the slip factor for design. The calculation is done assuming a 5 %-fractile from n=10 results with a confidence level of 75 %

$\boldsymbol{\mu_{5\%} = \mu_m - 2.05 \times s_\mu = \mu_m \times (1 - 2.05 \times V)}$

- V is the coefficient of variation, $V = \dfrac{s_\mu}{\mu_m}$
- μ_m is the mean value of the slip factor from ten measurements

$$\mu_m = \frac{\sum \mu_i}{n}$$

$$\mu_i = \frac{F_{si}}{4 \times F_{p,C}}$$

- F_{si} is the individual slip load
- $F_{p,C}$ is the specified preload level and = 0.7 $f_{ub}\,A_s$
  - f_{ub} is the tensile strength of the bolt
  - A_s = is the tensile stress area of the bolt
- n is the number of test specimens
- s_μ is the standard deviation of the slip factor

$$s_\mu = \sqrt{\frac{\sum(\mu_i - \mu_m)^2}{n-1}}$$

The SIROCO Project showed that the mean slip factor and coefficient of variation delivered a slip factor for design of 0.39 to 0.36 for hot dip galvanized coatings whip blasted to expose the Zn-Fe alloy layer. EN 1090-2 has been modified to allow for a slip factor of 0.35. When the same mean slip factor and coefficient of variation achieved in the European tests are inserted into to the Australian equations, the slip factor ranges from 0.37 to 0.35. So, while the formulae are not identical, the outcome appears close enough for designers to accept the SIROCO and EN 1090-2 approach for design in this case.

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The GAA has developed a series of Guides covering durability, sustainability, welding, and painting of hot dip galvanized steel. To download these Guides follow the link to gaa.com.au/technical-publications/

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