AUSTRALIAN STEEL INSTITUTE (ABN)/ACN (94) 000973 839 www.steel.org.au ASI TECHNICAL NOTE TN016 V1	**REF:** ASI TN016 Version 1 ASI Head Office Suite G1, Ground Floor 25 Ryde Road, Pymble NSW 2073 Tel: 02 8748 0180 Email: enquiries@steel.org.au **Author:** P W KEY **Date:** August 2023 Page 1 of 60

INSTALLATION OF BOLTED CONNECTIONS TO AS/NZS 5131

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SYNOPSIS

Bolted connections are fundamental to the structural integrity of steel structures. The engineer makes certain decisions regarding the intended behaviour of the connections (pinned/semi-rigid/ rigid) which affect the overall strength, stiffness and stability of the structural framing. The ability for connections to act with the intended behaviour is contingent in part on the prescribed method of installation being undertaken correctly.

The installation of bolted connections designed to AS 4100 (Ref. 1) is specified in AS/NZS 5131 (Ref. 2). Market feedback indicates the importance of correct installation procedures is not appreciated by steelwork riggers and incorrect procedures are often used. Consequently, there has been a demonstrable issue with the installation of bolted connections in Australia over the past years.

This Technical Note outlines the technical basis for and implementation of the bolt installation provisions of AS/NZS 5131 and is specifically intended to facilitate compliant outcomes for bolted connections for the Australian marketplace.

This Technical Note has been reviewed by a panel of industry stakeholders, as detailed in Section 20. Their support is gratefully acknowledged.

1.0 USING THIS DOCUMENT

The scope of this Tech Note is substantial, as it is designed to cover the full stakeholder chain and the relationships between the parties that are necessary to ensure duty of care for design, supply and installation of bolt assemblies for structural steel connections.

To clarify and simplify understanding for individual stakeholders of their role and duty of care, Section 18 of this Tech Note defines responsibilities and references a process flowchart in Appendix E, segmented into different stakeholder types and referenced back to the various sections in this Tech Note.

As an individual stakeholder in the process, you may choose to utilise the process flowchart to identify specific requirements within this document that are relevant to your role.

2.0 DEFINITIONS

Construction specification: set of documents covering technical data and other requirements for a particular steel structure, including those specified to supplement and qualify the provisions of this Standard (from AS 4100 Clause 1.3.16 and AS/NZS 5131 Clause 3.1.8)

/S, /TB, /TF: designator indicating the design basis for a bolt (from AS 4100 Table 9.2.1):

/S = bolt designed assuming the snug tight condition

/TB = bolt designed assuming the bolt is tensioned and resists loads at the ultimate limit state by bearing of the bolt on the connected plies

/TF = bolt designed assuming the bolt is tensioned and slip between the plies at the serviceability limit state is restricted

ILAC: International Laboratory Accreditation Cooperation. Refer International Laboratory Accreditation Cooperation (ilac.org)

PC: Property Class

MDR: Manufacturer Data Record

Plies: the plates in a connection that are brought together into contact by tightening of the bolt assemblies

Protected storage: storage of fasteners meeting the requirements of Clause 8.2.5 of AS/NZS 5131

Lot: A lot (number) is an alphanumeric code assigned by the manufacturer/distributor which identifies the manufacturer and the manufacturing lot number. Each diameter × length combination should have a separate lot number for traceability purposes.

SDoC: Supplier Declaration of Conformity; A document issued by the supplier declaring that the products supplied comply with the requirements of the relevant Australian Standard and that the documentation required by the Standard is available for issue (from AS/NZS 5131)

Trace code: A trace code is a short (typically 3 digit) alpha-numeric code which is linked to a bolt assembly's trace lot number (as defined in AS/NZS 1252.1). A trace code is marked on the product itself, typically the bolt head, enabling full traceability after the bolt assembly has left the box. Trace codes can be applied on other products including DTI washers.

3.0 CONTEXT

To expedite safe and cost-effective construction of steel structures, conventional wisdom suggests pre-fabrication in the workshop utilising welded connections and assembly on site utilising bolted connections. The veracity of bolted connections is consequently fundamental to the strength, stiffness and behaviour of the majority of structural steel framing utilised on building and infrastructure projects in Australia.

It is therefore surprising that market feedback from those that do understand bolted connection performance consistently indicates that there are problems in Australia with implementation of bolted connections on site. These problems may be broadly categorised into two areas:

- Supply of compliant bolt assemblies
- Installation of bolts, in particular high strength tensioned bolt assemblies

Historically, fastener quality has been one of the most overlooked aspects in construction and manufacturing in Australia, a complacency no doubt rooted in 100 years of relying on Australian manufacturers to supply fit-for-purpose product, manufactured to Australian Standards. Significantly, with local manufacture comes compliance to local consumer laws and a legal system that can reach any wayward manufacturers.

In the last 20 years, fundamental changes in our procurement environment, with increased competition, has resulted in virtually all local manufacturing ceasing and importation of the majority of structural bolts. Unfortunately, demonstrable cases of reduction in quality have ensued. Whilst quality product can undeniably be sourced internationally, it is also true that 'quality costs' and market pressure to reduce the cost of steel packages has resulted in predominantly price driven competition, where quality is demonstrated by a certificate whose veracity and/or appropriateness may be questionable. With legal recourse problematic and costly internationally, it is often left to a local party, usually the engineer, to 'certify' that the product meets the performance requirements of our Standards.

ASI has previously undertaken an initiative to help improve the quality of bolt supply in Australia, including championing the 2016 revision of AS/NZS 1252, with now AS/NZS 1252.1 (Ref. 3) covering product conformity and AS/NZS 1252.2 (Ref. 4) covering verification testing. The background and changes to AS/NZS 1252 are extensively outlined in ASI Tech Note TN001 (Ref. 5).

In respect of installation of bolted connections, in particular high strength tensioned bolt assemblies, a range of issues have been reported to ASI, including:

1. Bolt assemblies not performing as intended during tensioning, typically resulting in high installation forces and snapping of bolts in a torque failure mode. In some cases, bolt heads break off the shanks or threads strip. These are all indications of non-compliant bolt assemblies
2. Bolt assemblies not stored correctly on site, leading to dirty and/or corroded bolts being installed. The bolt condition markedly affects performance of the bolts during tensioning
3. No or incorrect application of lubrication. The presence, type and extent of lubrication can markedly affect the torque-tension relationship of the bolt assembly, resulting in incorrect tension in the completed bolt assembly. In extreme cases, torque failure of the bolt during tensioning may also occur
4. Gaps between matching faces of connection assemblies. If gaps remain after fully tensioning connections, the stiffness of the connection may be compromised, as well as the assumptions regarding the required friction force developed between the connected interfaces. Locally reduced stiffness caused by gaps can also affect some methods of tensioning, leading to incorrect tension values being applied
5. Bolted connections not being either snug tightened or tensioned adequately or uniformly around the connection. This speaks to a lack of understanding of the necessary tensioning process by installers
6. Bolt assemblies being over-tensioned, which may lead to local necking or thread stripping of the bolts. Often this may not be visible or obvious as a failure, leading to in-service bolts that have essentially failed
7. Incorrect use of direct tension indicators (DTI's) to measure tension applied to the bolt. This speaks to a lack of understanding of the equipment usage by the installers
8. Property class (PC) 10.9 bolts require additional care compared to property class (PC) 8.8 bolts in respect of ensuring compliant supply and installation process, due in part to the reduced ductility of property class 10.9 bolt assemblies

This Tech Note addresses these and other issues with installation of structural bolts and bolted connections, in particular high strength tensioned bolt assemblies.

4.0 THE BEHAVIOUR OF STRUCTURAL STEEL BOLTED CONNECTIONS

4.1 Context

It is important for stakeholders to understand the behaviour of structural steel bolted connections in order to appreciate and provide context to the requirements defined in AS/NZS 5131 (Ref. 2) for installation of bolted connections, in particular for connections utilising high strength tensioned bolt assemblies.

In AS 4100 (Ref. 1) there are three fundamental forms of construction defined:

1. Simple construction
2. Semi-rigid construction
3. Rigid construction

The required behaviour of the connections for these forms of construction is fundamentally predicated on the alignment of the connection and the type and tension status of the bolts utilised, as discussed next.

4.2 Simple construction

Clause 4.2.4 of AS 4100 states "For simple construction, the connections at the ends of members shall be assumed not to develop bending moments".

Regarding connections in simple construction, Clause 9.1.2.3 states "Connections between members in simple construction shall be capable of deforming to provide the required rotation at the connection. The connections shall not develop a level of restraining bending moment which adversely affects any part of the structure.

The rotation capacity of the connection shall be provided by the detailing of the connection and shall have been demonstrated experimentally. The connection shall be treated as being subjected to reaction shear forces acting at an eccentricity appropriate to the connection detailing".

Typical connections in simple construction, as detailed in the ASI 'Standardised structural connections' (Ref. 6), are shown in Figure 1. Of particular note:

- The connections have thinner plate elements, recognising rigidity is not required to maintain angles between members.
- The bolts are snug tight (/S) which allows the connected surfaces to slip relative to each other. For most simple connections, the bolts used are property class 8.8, taking advantage of the higher shear capacity of these bolts compared to commercial property class 4.6 bolts. Property Class 4.6 bolts may be used for smaller structures and connections, although it is recommended that different bolt types are not used on the same project, to minimise the chance of mixing up bolts in connections.
- The connections are detailed with clearances to allow a degree of rotation between the connected elements. This helps to minimise bending moments being developed through the connection.
- In some cases, for industrial structures subject to vibration, designers may opt to utilise /TB bolts. Tensioning of the bolts ensures the bolt assemblies do not loosen under vibration. In this case, the designers need to assure themselves that the behaviour of the /TB bolt does not invalidate the behavioural assumptions inherent in the design model for the connection

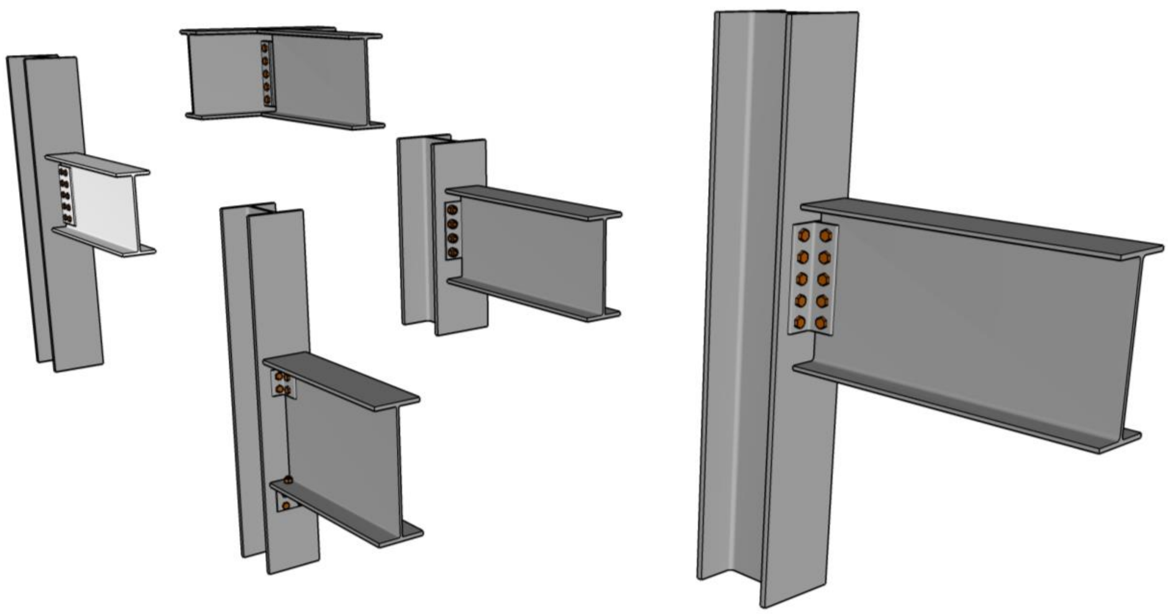


Figure 1 Typical connections in simple construction

4.3 Semi-rigid construction

Clause 4.2.3 of AS 4100 states "For semi-rigid construction, the connections may not have sufficient rigidity to hold the original angles between the members unchanged, but shall be assumed to have the capacity to furnish a reliable known degree of flexural restraint.

The relationship between the degree of flexural restraint and the level of the load effects shall be established by methods based on test results".

Regarding connections in semi-rigid construction, Clause 9.1.2.2 states "Connections between members in semi-rigid construction shall provide a predictable degree of interaction between members, based on the actual action-deformation characteristics of the connection as determined experimentally".

It is not that usual for semi-rigid connections to be designed, but the option is available where, through necessity, engineers need to detail connections that require some degree of rigidity but cannot be classified as fully rigid.

An example of a connection that might be classified as semi-rigid (if the engineer needs to take some account of connection rigidity in the structural model for the frame) is the framing connection shown in Figure 2. The beam member is connected to the face of the column member and this joint may deform under applied bending moment, due to the bolted angles deforming as shown. In this case, the engineer would need to undertake an analysis to ascertain the moment-rotation characteristics of the connection and use this in the overall structural frame model.

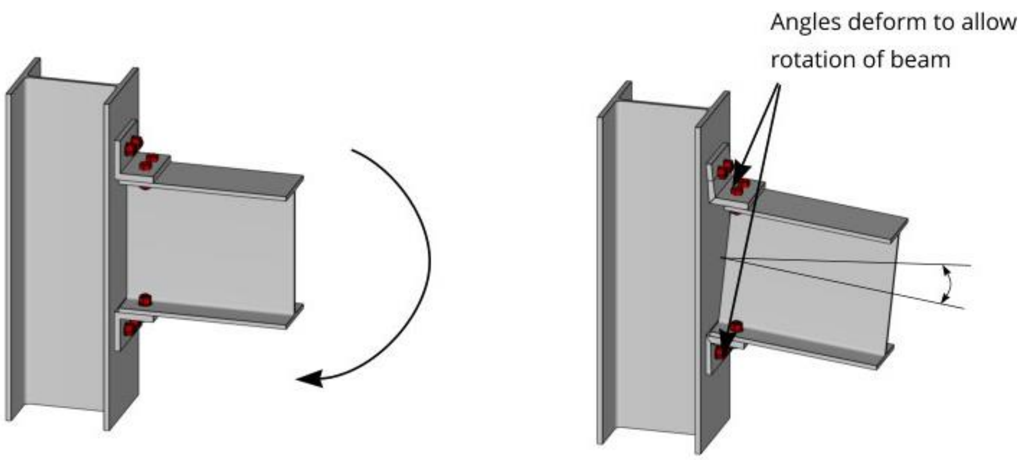


Figure 2 Example of a semi-rigid connection

4.4 Rigid construction

Clause 4.2.2 of AS 4100 states "For rigid construction, the connections shall be assumed to have sufficient rigidity to hold the original angles between the members unchanged".

Regarding connections in rigid construction, Clause 9.1.2.1 states "The joint deformations shall be such that they have no significant influence on the distribution of action effects nor on the overall deformation of the frame".

Typical connections in rigid construction, as detailed in the ASI 'Standardised structural connections' (Ref. 6), are shown in Figure 3. Of particular note:

- The connections have relatively thick plate elements and/or stiffeners, which ensures they are stiff enough to transmit the applied forces and bending moments without undue deformation, hence minimising any change in angle between the connected members
- Bolts are high strength (typically property class 8.8 but may also be property class 10.9) and are fully tensioned, acting in bearing mode (/TB). The design models have been verified against physical testing with /TB mode bolting. /TF mode is generally not required

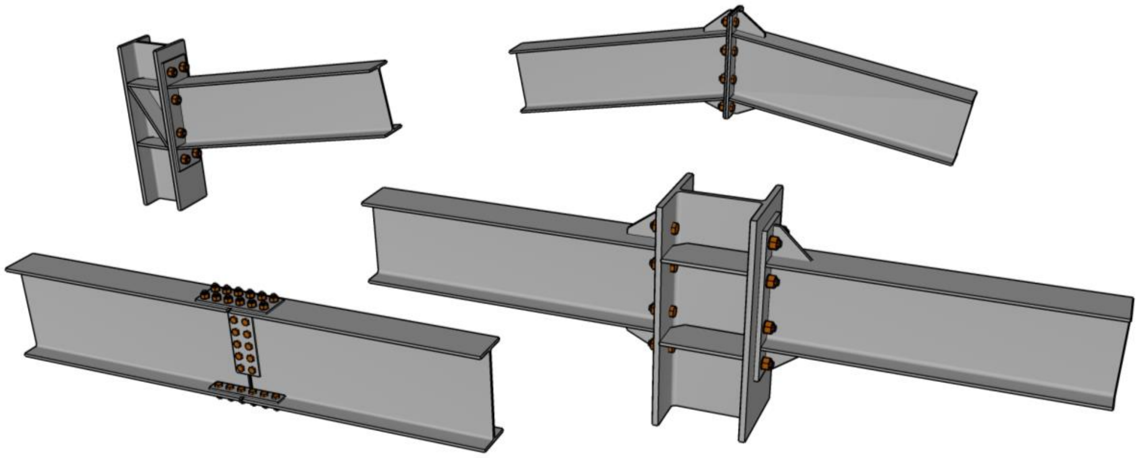


Figure 3 Typical connections in rigid construction

4.5 Basis for design models

It is important to note that with these connection types, the design models have been developed based on extensive experimental testing and numerical modelling, to ensure the performance intent of the requirements in AS 4100 is maintained.

The theoretical background, design models and design capacity tables for the range of standardised structural connections, both simple and rigid, are extensively documented in the ASI Simple and Rigid connections suite of handbooks (Refs. 7, 8).

5.0 AS/NZS 5131 CONTEXT

As referenced from AS 4100, AS/NZS 5131 ‘Structural steelwork – Fabrication and erection’ (Ref. 2) provides the implementation requirements for installation of bolted connections, consistent with the design philosophy provided in AS 4100.

The relevant sections include:

For bolting materials:

- **Clause 5.5.3 Structural fasteners for other than tensioned applications**: provides reference to Standards for bolts, nuts and washers for normal strength assemblies, often referred to as ‘commercial’ or ‘black’ bolts. Commercial Property Class 4.6 structural bolts are typically used for small fitments and low load applications.
- **Clause 5.5.4 Structural bolt assemblies for tensioned applications**: references AS/NZS 1252.1 for high strength bolt assemblies
- **Clause 5.5.5 Direct tension indicators**: references ASTM F959 (Ref. 9) for compressible washer type direct tension indicators and associated hardware

For connection component configuration:

- **Clause 6.5 Cutting**: provides requirements for roughness of cut and treatment of cut edges
- **Clause 6.7 Holing**: provides requirements for hole sizes, oversize and slotted holes and use of plate washers
- **Clause 6.9 Assembly**: references Appendix F for tolerances on components of the assembly. This is particularly relevant for flatness of mating surfaces and the like.

For assembly of bolted connections:

- **Clause 8.1.2 Quality Management System**: requires a quality management system is operated for mechanical fastening
- **Clause 8.1.3 Work method statements**: requires a documented Work Method Statement (WMS) to be prepared for mechanical fastening
- **Clause 8.2 Bolts, nuts and washers**: defines requirements for application of packers and shims, clear threads above nuts, locking devices for nuts, application of washers and plate washers and storage of bolt assemblies

For preparation of contact surfaces:

- **Clause 8.4 Preparation of contact surfaces on connected plies**: Clause 8.4.1 provides requirements for surface condition, removal of burrs and applied finishes, including galvanizing. Clause 8.4.2 provides requirements specific to friction-type connections, in particular the treatment of the contact surfaces

For snug tightening of bolted connections:

- **Clause 8.3 Snug-tightening of bolts**: provides requirements for insertion of bolts, tightening to snug-tight condition, tightening sequence and the use of lock nuts.

For tensioning of high-strength bolts:

- **Clause 8.5 Tensioning of high-strength bolts**: provides requirements for use of competent personnel, tensioning pattern, the minimum bolt tension to be achieved, the part-turn method of tensioning, tensioning using direct tension indicators (DTI's) and, in particular, use of compressible washer-type DTI's.
- **Clause 8.7 Use of specialised fasteners and fastening methods**: provides requirements when using fastening methods other than those defined in the Standard. Particular reference is made to twist-off-type tension control bolt assemblies for tensioned connections

These requirements are referenced in the following sections of this document.

6.0 BOLT ASSEMBLY BASICS

6.1 Functional requirements

Steel structures are required to be assembled on site and the most convenient and cost-effective approach is generally considered to be using bolted connections. Usually, the bolted connections are configured such that the bolts clamp together two flat steel plates, one on each of the members to be connected. These plates are often termed the connected 'plies'. The amount of clamping may be minimal (a 'snug-tight' connection) or there may be a defined level of clamping force applied (a 'tensioned' connection).

An individual bolting 'assembly' comprises a bolt, a nut and at least one washer, as further described in Section 6.2.

In any one connection, a structural bolting assembly resists load in one or a combination of three ways, as shown in Figure 4:

- **Direct shearing on the shank of the bolt**: forces applied in the plane of each plate cause shearing across the shank of the bolt. This shearing may occur on either the threaded or unthreaded portion of the bolt shank, depending on the length of thread and the thickness of the connected plies
- **Direct tension on the bolt**: forces in the connected plies tend to 'open up' the connection, causing the bolt assembly to go into tension

- **Shear on the connecting faces of the plies**: in this case the clamping force in the tensioned bolts is sufficient to mobilise friction between the faces of the connected plies, which transfers the shear load across the connection, rather than relying on the bolts to take the shear force directly as noted above.

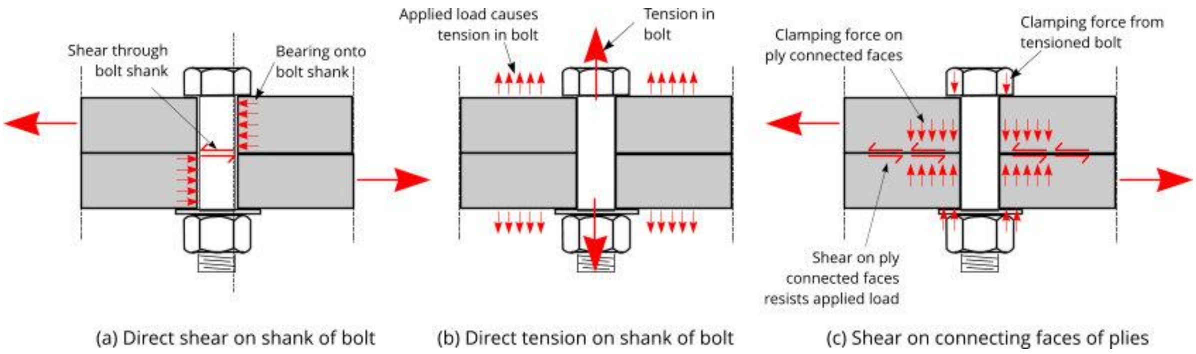


Figure 4 Bolt assembly load resistance mechanisms

6.2 Bolt Assembly Terminology

For the purposes of subsequent discussion, it is appropriate to define a range of terminology as shown in Figure 5.

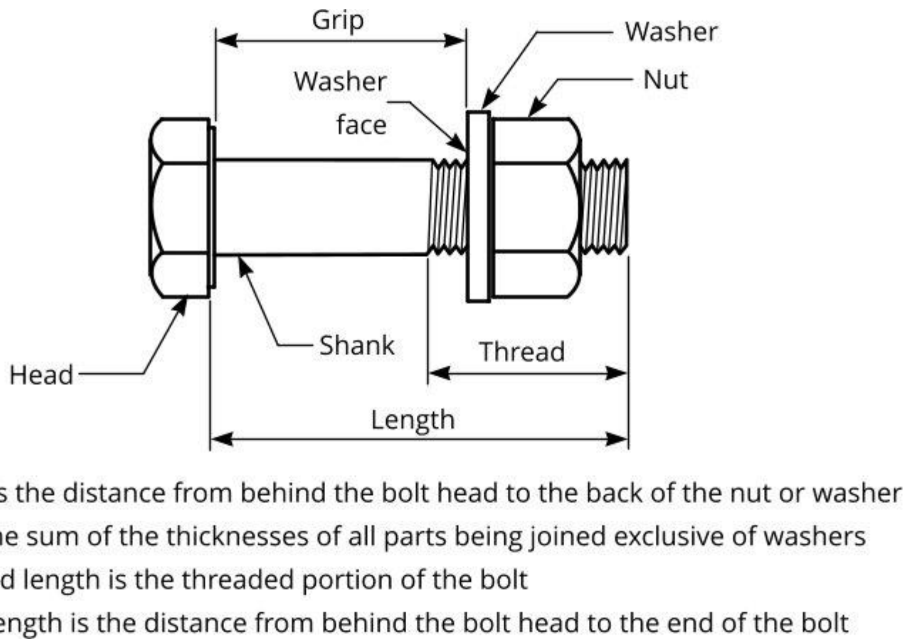


Figure 5 Bolt assembly terminology

7.0 BOLT TYPES, IDENTIFICATION AND TRACEABILITY

7.1 Bolt Types

AS 4100 references three distinct types of structural bolts:

- Commercial bolts: referenced to Standards AS 1110 series (Ref. 10), AS 1111 series (Ref. 11), AS 1112 (Ref. 12) and AS 1237.1 (Ref. 13) The property class nominated is 4.6
- High strength property class 8.8 bolt assemblies: Referenced to AS/NZS 1252.1 (Ref. 3)
- High strength property class 10.9 bolt assemblies: Referenced to AS/NZS 1252.1

The fundamental differences in strength related properties between these bolt types are provided in Table 1. A more detailed description, including capacities of the different bolt sizes, is provided in Tech Note TN001 (Ref. 5).

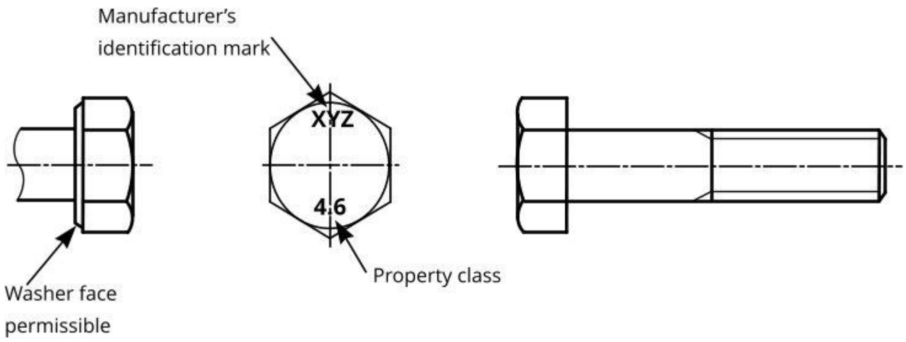
Table 1 Bolt types and strength properties

Property	**Commercial Property Class 4.6**	**High strength Property Class 8.8**	**High strength Property Class 10.9**
Ultimate tensile strength	400 MPa	830 MPa	1040 MPa
Yield strength (MPa)	0.6 x 400 = 240 MPa	0.8 x 830 = 664 MPa	0.9 x 1040 = 936 MPa

Given the fundamental strength differences between commercial bolts and property class 8.8 and 10.9 bolts, it is important to properly identify bolt assemblies on site and ensure the correct bolts are used in the correct connections. It is also important to ensure that the bolt assemblies are traceable to compliant supply.

7.2 Identification – bolts not for tensioning

The usual head designation of commercial bolts to AS 1111 is illustrated in Fig. 6(a) and an actual example in Fig. 6(b). For the material strength, AS 1111 references AS/NZS 4291.1 (Ref. 14) Property Class 4.6, which also defines the head marking. It is important to note that AS/NZS 4291.1 covers a range of property classes, including 3.6, 4.6, 4.8, 5.8, 6.8, 8.8, 9.8, 10.9 and 12.9. Therefore, a bolt that looks similar to one defined in AS 1111 may have a Property Class of, for example, 8.8, indicating a higher strength bolt. However, these bolts are NOT designed for tensioning. They have a smaller head size that will not accept the torque applied during tensioning. High strength bolts designed for tensioned connections must meet the requirements of AS/NZS 1252.1.



(a) Example head designation

(b) Image of typical bolt head

Figure 6 Example head designation of bolts to AS 1111

7.3 Identification – bolts able to be tensioned

Bolt assemblies that are able to be tensioned are manufactured to the requirements of AS/NZS 1252.1.

AS/NZS 1252.1 references three different bolt types:

- **Bolt assemblies to AS/NZS 1252.1**: These are property class 8.8 and are historically the type used for most steel structures in Australia
- **Alternative assembly type to EN 14399-3 System HR**: these are property class 8.8 and manufactured to EN 14399-3 System HR (Ref. 18)
- **Additional assembly type to EN 14399-3 System HR**: these are property class 10.9 and manufactured to EN 14399-3 System HR (Ref. 18)

The 'Alternative' and 'Additional' assembly types were introduced to allow procurers to have an expanded selection of high strength bolt assemblies. The performance attributes (strength, ductility etc) of these bolt assemblies are virtually identical to the high strength bolts used historically in Australia. A full explanation of the background and technical details is provided in ASI Tech Note TN001 (Ref. 5).

The marking of the three different bolt assembly types is shown in Figure 7. Practically, on site either of these bolt types may be used. However, the bolt assembly components must not be mixed and it is strongly recommended that only one bolt type is used on a site.

Figure 8 shows actual AS/NZS 1252.1 and alternative property class 8.8 bolt assemblies.

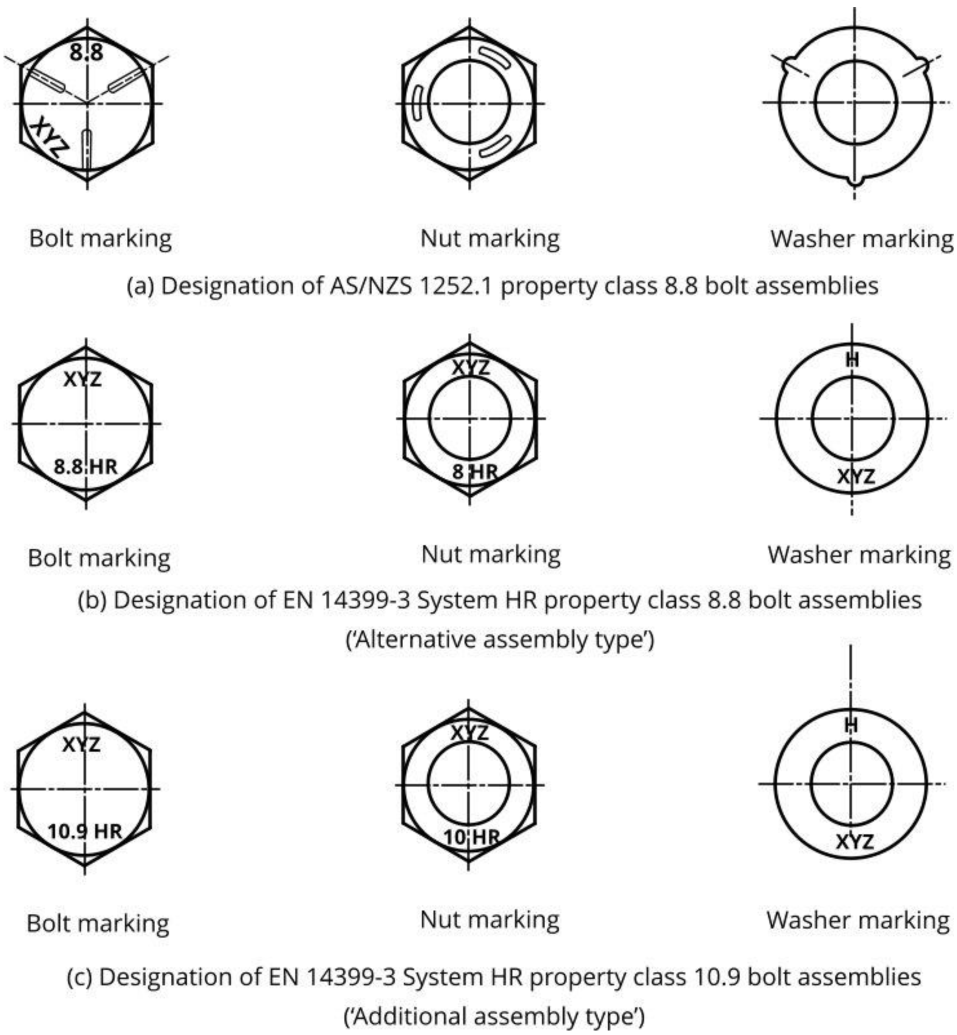


Figure 7 Bolt, nut and washers markings for high strength bolt assemblies

7.4 Packaging

For high strength bolts designed for tensioned applications, AS/NZS 1252.1 requires that:

- bolt assemblies are supplied to the purchaser either in the original unopened single sealed container or alternatively in the separate sealed containers of the manufacturer of the assemblies.
- The nuts, bolts and washers are supplied as a complete assembly from the one manufacturer.
- Mixing of different bolt assembly types in the same box is not permitted.

The delivery condition of high strength bolts is critical to the intended performance characteristics, in particular with regard to tensioning. Clean, dry unbroken packaging helps to ensure the intended surface condition is maintained. Similarly, storage and treatment on site must ensure the as-received condition of the assemblies is maintained.

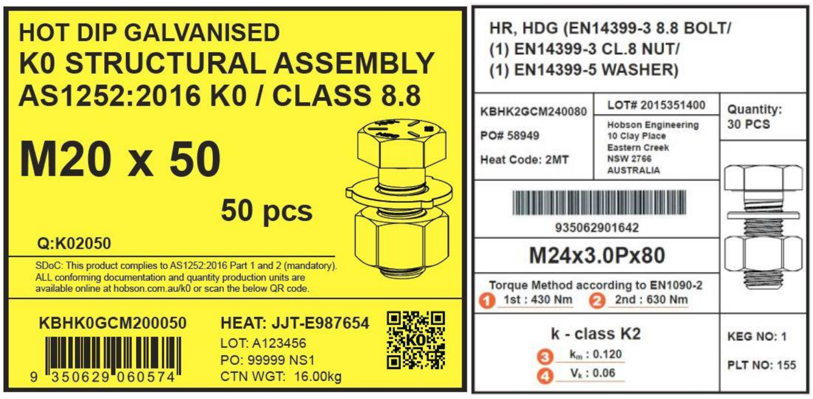
Each package or box shall be clearly identified with the product designation, the name and address of the manufacturer or supplier, batch and heat identification number from which the bolt, nut and washer were taken, the k-class (where not shown, K0 shall be assumed) and a manufacturing or trace lot number. An example of labels on packaging is shown in Fig. 9.

(a) AS/NZS 1252.1 property class 8.8 bolt assembly components

(b) EN 14399-3 System HR property class 8.8 bolt assemblies

Figure 8 Example bolt assemblies

(a) Property Class 4.6 bolts to AS 1111.1



(b) Property Class 8.8 bolt assemblies K0 to AS/NZS 1252.1 and K2 to EN 14399-3

Figure 9 Example packaging labels for bolt assemblies

7.5 Traceability

A lot number is an alphanumeric code assigned by the manufacturer/distributor which identifies the manufacturer and the manufacturing lot number. Each diameter × length combination should have a separate lot number for traceability purposes.

It is essential that bolt importers/distributors, fabricators and erectors ensure traceability of the bolts used in a particular project by way of identifying each bolt diameter × length combination using the lot number on the box in which the bolts are supplied. The location where each lot number of bolts is used on the steel frame should also be recorded because once the bolts are removed from the box, they are no longer traceable unless a record is kept of what bolt diameter × length combination went where.

Although a unique head marking depicting a “trace code” is not a requirement of the standard, it is offered by a number of suppliers in the Australian market and does offer an extra level of traceability to the ILAC test reports, product labelling and head marking.

Ensuring traceability of bolt assemblies through to location in the final structure should be actioned by the constructor with procedures defined in the Inspection and Test Plans (ITP’s). A record of this should be included as part of the as-built documentation.

8.0 ASCERTAINING COMPLIANCE OF BOLT ASSEMBLIES

8.1 Context

The quality of high strength bolt assemblies critically influences installation outcomes, in particular where the bolt assemblies are tensioned. It is therefore important that bolt installers understand how to establish the compliance of bolt assemblies that are to be installed. Defective bolt assemblies compromise the structural integrity of the building or structure. Replacement of defective bolt assemblies can be costly and impact project schedule. Failure of bolt assemblies during installation can increase the health and safety risks for installers, as the tensioning energy stored in the bolts can be suddenly released when failure occurs.

For these reasons, installers should confirm, so far as is reasonably practical, the compliance of the bolt assemblies they are about to install. The best way to do this is to critically review the documentation provided with the bolt assemblies.

8.2 Information that should be supplied

Where bolts have been supplied to AS/NZS 1252.1 the following information should be expected:

From the bolt manufacturer:

The bolt manufacturer must be able to supply one or both of the following documents:

(a) Product certification from an internationally recognised third-party accreditation scheme including details of audits conducted. All information required under AS/NZS 1252.1:2016, AS 4291.1:2015 (Ref. 14) and AS/NZS 4291.2:2016 (Ref. 15) should be provided for each lot, the type and number of tests for each lot being in accordance with Section 6 and Appendix B of AS/NZS 1252.1:2016.

(b) Results from a sampling and testing plan for each lot that complies with Section 6 and Appendix B of AS/NZS 1252.1:2016. All information required under AS/NZS 1252.1:2016, AS 4291.1:2015 and AS/NZS 4291.2:2016 should be provided for each lot.

Note that a lot for this purpose is defined as a bolt diameter and length from a particular heat of steel from a process with factory production control (FPC). Each lot should be identified for traceability according to the requirements of AS/NZS 1252.1.

From the bolt importer/distributor:

The bolt importer/distributor must be able to supply the above information from the bolt manufacturer if requested. A Supplier Declaration of Conformity (SDoC) letter stating compliance with AS/NZS 1252.1:2016, AS 4291.1:2015 and AS/NZS 4291.2:2016 should be provided for each lot.

If the bolt importer/distributor cannot supply the above information from the bolt manufacturer, then the importer/distributor is obliged to undertake a sampling and testing programme using an ILAC accredited laboratory and supply the results from a sampling and testing plan for each lot. The importer/distributor should also provide the SDoC referencing the tests undertaken.

The procurer should insist that the above documentation for each lot be supplied when the bolts themselves are supplied. This should form a part of their Quality Assurance programme. The procurer can engage a laboratory to undertake independent testing if so desired to verify the information supplied or to obtain any information that is missing.

Table 2 indicates the minimum level of information that should be in the possession of the erector/installer.

TABLE 2 Minimum level of information

Item
Identification and address of the supplier
Identification and address of the test laboratory and accreditation details of the test laboratory, details of laboratory accreditation
Date of issue, page number on each page
Test certificate number
Batch and heat identification number for each lot
Product identification for each lot
Customer purchase order number and heat number for each lot
Any other system reference numbers. These make sure that the product is fully traceable from the customer purchase order to the original steel used for its production.
Test, test specification, measured values in comparison to specification of all properties listed in the Appendix to this Technical Note for each lot
Statement of full compliance referring to Australian Standard AS/NZS 1252.1:2016 for each lot (SDoC)
Signature of authorised officer/position/name/date/accreditation
Any further information or tests that may be requested or as agreed with the supplier but may incur extra cost.

NOTE: All information should be in alphanumeric English. A 'lot' for the purpose of this Table is defined as a bolt diameter and length from a particular heat of steel.

9.0 SITE HANDLING OF FASTENER COMPONENTS

9.1 Protected Storage of Fastener Components

Clause 8.2.5 of AS/NZS 5131 provides requirements for storage of fastener components. The main requirements include:

- The components shall be protected from dirt and moisture in closed containers at the location where the components are to be installed
- Only the required number of fastener components shall be taken from protected storage at any one time
- Unused fastener components shall be returned to protected storage
- Fastener components shall not be modified from the as-delivered condition, except for removal of moisture and dirt using a soft brush

The surface condition of high strength bolts intended to be tensioned can significantly influence the tensioning performance, as is detailed subsequently. Dirt and corrosion can dramatically increase the friction between the bolt and nut threads and lead to torque-initiated failures during tensioning. Refer to Appendix B for a discussion on why bolts break during tensioning.

The requirements for protected storage of fastener components are designed to ensure they remain fit-for-purpose in the as-manufactured condition. Regardless, extended periods of storage and exposure to heat and the like may affect the lubrication supplied with the fasteners. Pre-installation verification, as referenced subsequently and detailed in Appendix C, will help identify any issues that may require re-conditioning of bolt assemblies.

9.2 Re-conditioning of Bolt Assemblies

Where circumstances require the bolt assemblies to be cleaned and re-conditioned:

- For bolt assemblies intended to be tensioned using either the part-turn method or DTI method, after thorough cleaning, the assemblies must be lubricated to manufacturer recommendations or equivalent. Pre-installation verification (refer Appendix B) must be undertaken on a representative sample of the cleaned and lubricated bolt assemblies.
- For bolt assemblies intended to be tensioned using a torque-controlled method, after thorough cleaning, the assemblies must be lubricated to manufacturer recommendations or equivalent. Pre-installation verification must be undertaken on a representative sample of the cleaned and lubricated bolt assemblies. The k_m or 'nut factor' may change from that provided on the bolt assembly packaging due to the cleaning and re-lubrication. Therefore, pre-installation verification will provide the installation torque required, rather than utilising the k_m value to calculate the installation torque.

Some specialised high strength bolt assemblies, including tension control bolts, must not be re-lubricated on site but must be returned to the manufacturer for cleaning, lubrication and re-calibration. Check the manufacturer instructions in this regard.

10.0 ASSEMBLY OF BOLTED CONNECTIONS

10.1 Connection component checks

Prior to assembling a bolted connection, the components must be checked to ensure they will come together correctly, seat firmly and resist loads according to the connection behavioural model (/S, /TB, /TF) documented by the engineer on the design drawings and/or specification.

The checks include:

- Cutting: roughness of cut edges, treatment of edges, condition of corrosion protection (paint, galvanizing etc)
- Hole configuration: Size, location, edge distance and configuration of bolt holes match that documented in the construction specification and are consistent across connected interfaces
- Holing: size and roundness of holes, presence of burrs etc
- Alignment: Alignment and flatness of contact surfaces
- Slotted holes: use of appropriate plate washers

As noted previously, AS/NZS 5131 provides guidance on these aspects.

Whilst the majority of these checks should have been undertaken as part of quality control in the fabrication shop prior to shipment to site, the ITP should include checks of these components on site to minimise time consuming disassembly and/or rework after the components are in position.

10.2 Traceability

As noted previously, ensuring traceability of bolt assemblies through to location in the final structure should be implemented by the builder, with procedures defined in the Inspection and Test Plans (ITP's). The bolting supervisor should ensure records are maintained. These records should be included as part of the as-built documentation and manufacturer data record (MDR).

10.3 Preparation of contact surfaces

The condition of the contact surfaces of connected plies requires particular attention, especially where the connection has been designed as a tensioned connection relying on friction between the connected ply surfaces (/TF connection type).

For all contact surfaces:

- Remove all oil, dirt, loose scale, loose rust, burrs, foreign material and any other defects on the surfaces to be in contact that might prevent solid seating in the snug-tightened condition
- A clean 'as rolled' surface with tight mill scale adhering is an acceptable surface condition

For contact surfaces on snug-tightened connections (/S):

- Contact surfaces with undercoat or galvanizing is acceptable and, in many cases preferable, to help ensure a degree of corrosion protection on interfaces that may not be completely closed in the snug-tight condition.

For contact surfaces on tensioned connections designed for bearing mode (/TB):

- Contact surfaces with undercoat or galvanizing is acceptable, since the frictional resistance on the interface is not a requirement of the design model for this connection type. Thick coats of paint should be avoided, as they may gradually compress when the bolts are tensioned and lead to loss of effective pretension in the connection.
- Particular attention should be paid to the degree of cure of any paint system used on the surfaces. Connections should only be tensioned when the paint has completely cured, to avoid potential loss of effective pretension from gradual compression of the paint layer. Table 3 provides indicative cure times for different paint systems.

Table 3 Indicative curing times for different coating systems

Coating system	Minimum curing time (days)
Organic zinc-rich primer	9
Organic zinc-rich primer + epoxy topcoat	9 + 7
Inorganic zinc-rich primer	3
Inorganic zinc-rich primer + vinyl topcoat	3 + 18
Vinyl primer	17
From: Report No. FHWA/RD-81/148 'An experimental study of bolted shear connections'	

For contact surfaces on tensioned connections designed for friction mode (/TF):

- shall be clean 'as rolled' surfaces or equivalent, and shall be free from paint, lacquer, galvanizing or other applied finish unless the applied finish has been tested to establish the friction coefficient
- where the contact surfaces in a /TF connection have an applied finish, the construction specification should be checked to ensure these finishes have been specified. If no finish has been specified, the surface finish must be approved by the design engineer prior to

assembly of the connection or the surface finish removed back to the equivalent of a clean 'as rolled' surface. Clause 8.4.2 of AS/NZS 5131 provides guidance on the areas on the connected interface where the applied finish must be removed. Refer also to Figure 15.

10.4 Assembly

The assembly of a bolted connection should be straightforward, provided the preceding checks have been undertaken. The assembly process prepares the connection for snug-tightening of the bolts.

The important steps in the assembly process are:

- Align bolt holes to permit insertion of the bolts without damage to the bolt threads. A drift pin or pins the same diameter as the bolts should be used to maintain alignment whilst the bolts are inserted
- Insert the bolts, paying particular attention to the direction of insertion, which may be influenced by:
    - Equipment clearances for subsequent snug-tightening or tensioning
    - Whether threads are included or excluded from the shear plane (refer later discussion)
    - Any particular view requirements associated with architecturally exposed structural steelwork. The construction specification should define this, where required
- Assemble the washers, nut and any required DTI's, paying particular attention to correct placement of all items. AS/NZS 5131 Clause 8.2.4 requires one washer to be placed under the part (bolt head or nut) that is to be rotated during tightening, as shown in Figure 10. Refer later for discussion on DTI placement
- Run all nuts up the bolt shaft until finger tight. Check for any thread damage if nuts cannot be run up by hand and replace where necessary
- Visually inspect connection to ensure all bolt assemblies are installed and correct placement of all items

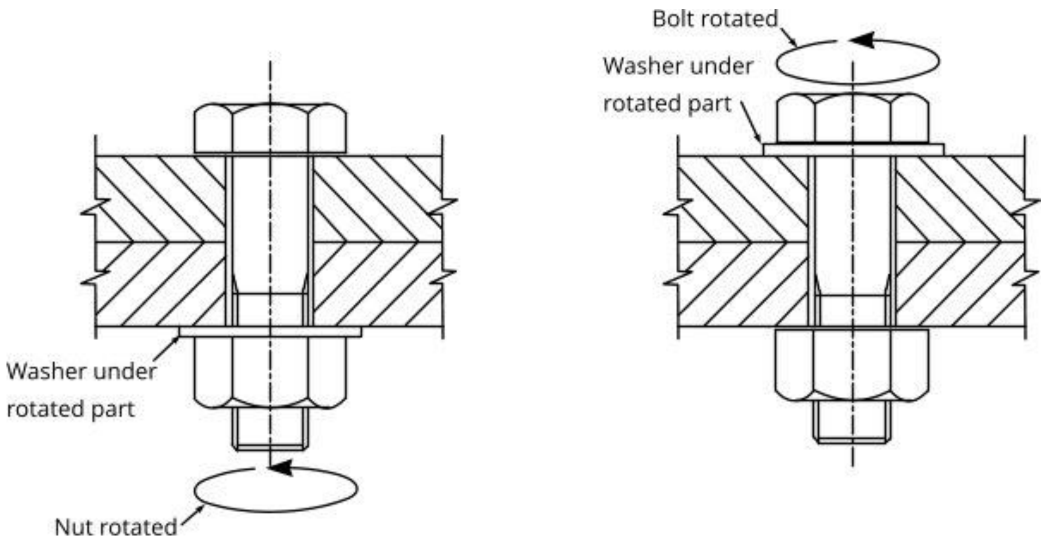


Figure 10 Washer placement

10.5 Threads included or excluded from the shear plane

The shear resistance of a bolted connection, in particular snug tight connections, is in part a function of shearing across the interface of the connected plies, which puts the bolt shank into direct shear, as shown in Figure 11.

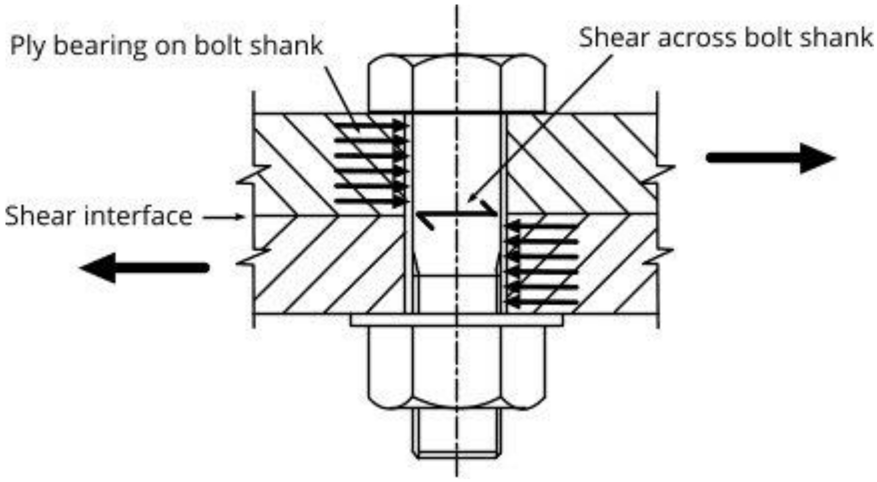
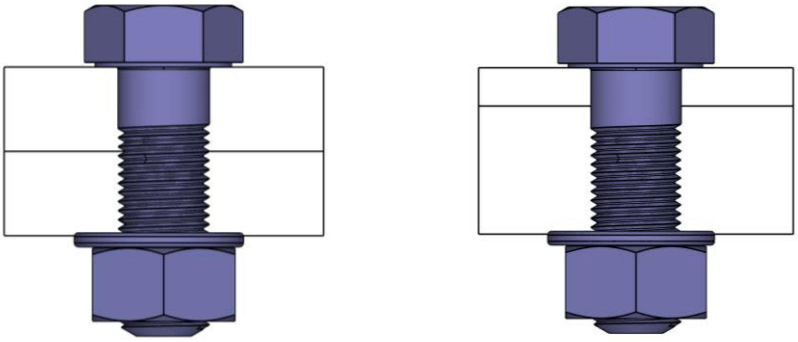


Figure 11 Bolt shank in shear

The strength of the bolt shank in shear is a function of whether the shear is applied across the threaded or unthreaded portion of the bolt shank. The unthreaded bolt shank has a higher shear capacity than the threaded bolt shank. Therefore, the design shear capacity of the bolted connection due to bolt shear is different, depending on whether the threads are included or excluded from the shear plane.

Figure 12(a) shows the case of threads included in the shear plane and Figure 12(b) the case of threads excluded from the shear plane.

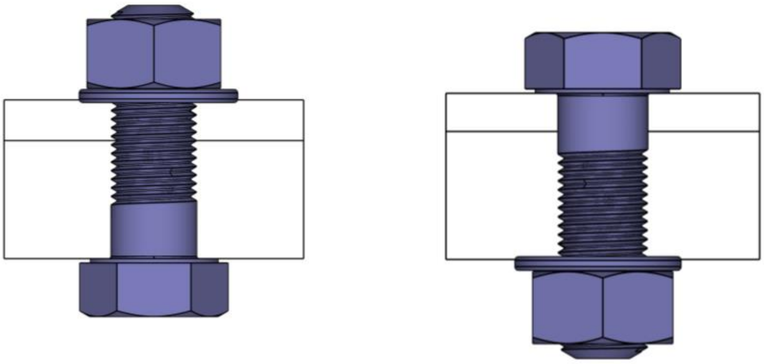


(a) Threads included in shear plane (b) Threads excluded from the shear plane

Figure 12 Threads included and excluded from the shear plane

It is important to note that in certain circumstances, whether threads are included or excluded from the shear plane depends on the direction of bolt insertion into the hole. Figure 13 shows the same bolt and plate material thickness configuration, except that the bolt is shown inserted from two different directions. In one case the threads are excluded and in the other case they are included.

In the majority of cases, where not otherwise indicated, the engineer will have designed the connection based on the more conservative assumption of the threads included in the shear plane. <u>However, the construction specification should be reviewed specifically to ascertain if there are any special requirements to exclude the threads from the shear plane and therefore if the direction of bolt insertion must be checked</u>. For most standard bolt shank configurations and usual thicknesses of plates being connected, the threads will be included in the shear plane. Particular attention must be paid if threads are defined in the construction specification to be excluded.



(a) Threads included in shear plane (b) Threads excluded from the shear plane

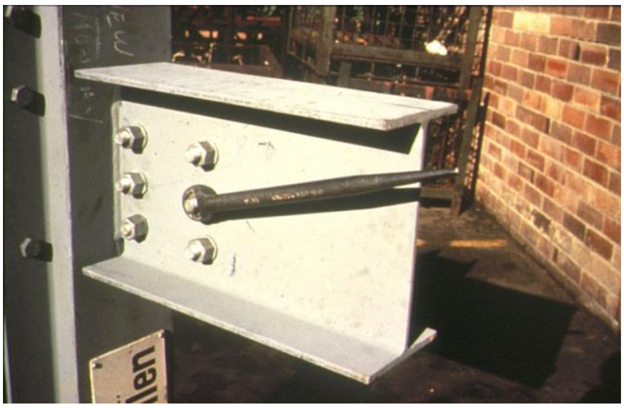
Figure 13 Direction of bolt insertion can influence thread alignment with shear plane

11.0 SNUG TIGHTENING OF BOLTED CONNECTIONS

11.1 Degree of snug tightening

The snug tightening of bolts brings the connection into the final condition (/S) for the connections used in simple construction noted previously. Snug tight is also the starting point for the tensioning of bolted connections discussed in the following section.

'Snug tight' is defined in AS/NZS 5131 Clause 3.3.4 as "The tightness in the bolts in a bolted connection attained by a few impacts of an impact wrench or by the full effort of a person using a standard podger spanner to bring the plies into firm contact". As indicated in Figure 14, standard podger spanners have a length related to the size of bolt to be tightened, with longer spanners on larger bolts providing more torque on the nut.



M20 Podger approx. 450mm long
M24 Podger approx. 600mm long

Figure 14 Standard podger spanner application

For bolt assemblies intended to be tensioned subsequent to the snug tightening, and given the relative preciseness of the requirement for application of a defined tension in the bolt assemblies discussed in subsequent sections, there are concerns raised regularly by stakeholders that the snug tightening procedure appears decidedly imprecise, with significant variation in the degree of snug tightness possible. For example, the operator on the podger spanner may apply different pressure depending on their size and strength.

Appendix A provides an analysis of the behaviour of bolt assemblies during tensioning and indicates that, due to the fact that the bolt material, in particular in the threads, yields under the tensioning loads applied, the final tension achieved in the bolt is relatively insensitive to the degree of snug-tightness.

11.2 Firm contact

An important performance requirement for a snug tightened connection is that the plies are brought into 'firm contact'. AS/NZS 5131 Clause 3.1.16 defines firm contact as "The condition that exists between plies in a bolted connection where the plies are solidly seated against each other, but not necessarily in continuous contact, over the effective firm contact area".

AS/NZS 5131 does not specifically define what it considers the 'effective firm contact area' to be. However, it does prescribe requirements for what is considered to be the effective area to be free of applied finishes where friction is required to be developed in a /TF connection, as shown in Figure 15.

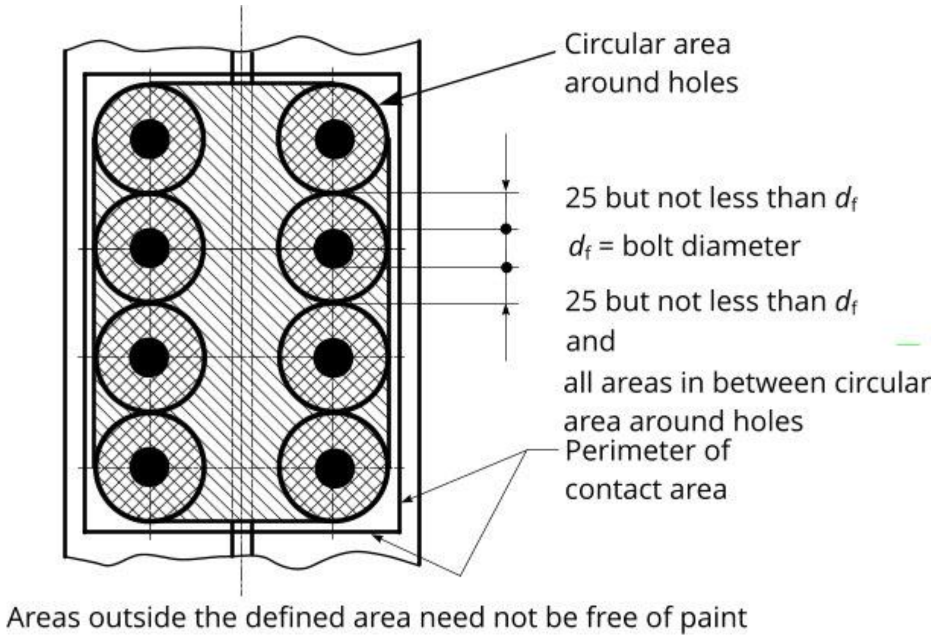
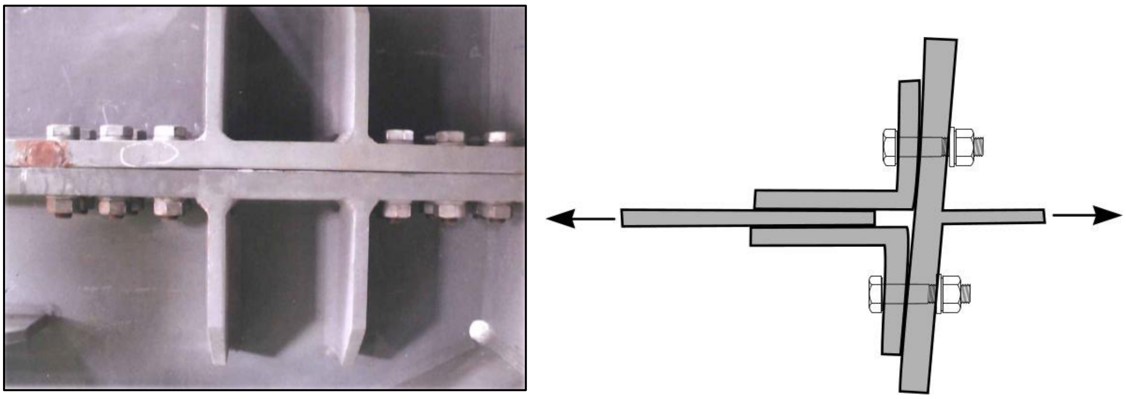


Figure 15 Effective contact area

Examples of gaps that are considered acceptable are shown in Figure 16 and gaps in connections not considered acceptable are shown in Figure 17.

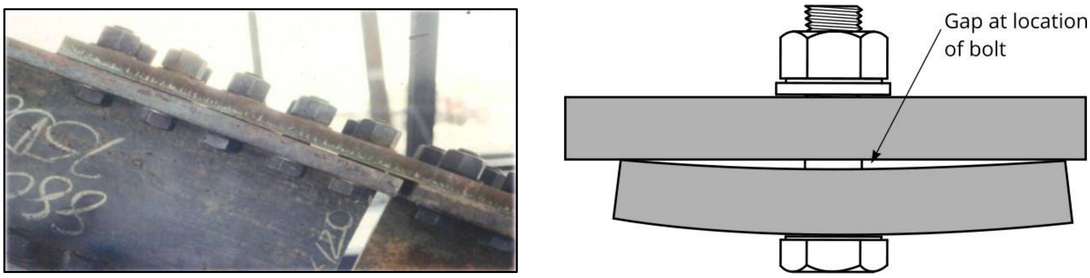
In Figure 16(a), whilst a gap is discernible between the end plates at the location of the stiffeners, there is no apparent gap in the area of the two bolt groups. In Figure 16(b) there is no gap around the location of both bolts. These bolts would not be considered a bolt group, as they are connecting two separate components. Therefore, gaps outside the area of the individual bolts are acceptable and the connection should not be assessed as a bolt group in the manner illustrated in Figure 15.



(a) (b)

Figure 16 Gaps considered acceptable

In Figure 17(a) there is a clear gap between the flange of the I-beam and connection plate in what would be considered the effective area of the bolt group. In Figure 17(b) there is a gap directly at the location of the bolt.



(a) (b)

Figure 17 Gaps not considered acceptable

11.3 Effect of gaps on tension developed

AS/NZS 5131 requires snug tightened interfaces to have no or minimal gaps over the effective contact area in order to ensure that when the bolt is tensioned the material between the bolt and nut (the 'grip' shown in Figure 5) is stiff and responds largely with a stiffness similar to solid steel. The reason for this is that the part-turn method of tensioning (discussed subsequently) relies on a direct relationship between the amount the nut is turned and the tension that is developed in the bolt (and hence the clamping force between the connected plies). If there is any sponginess in the grip, which would be the case if a gap exists, then this relationship can be significantly impacted, with lower tension loads applied than required. The graph in Figure 18 provides an indication of the effect. For example, from Figure 18, for the case of low grip stiffness, at around ½ turn applied to the nut, the bolt stress is reduced from around 830 MPa to around 500 MPa, a significant 40% reduction.

It is therefore important that firm contact is maintained and any gaps in the effective contact area of the snug tight connection are eliminated.

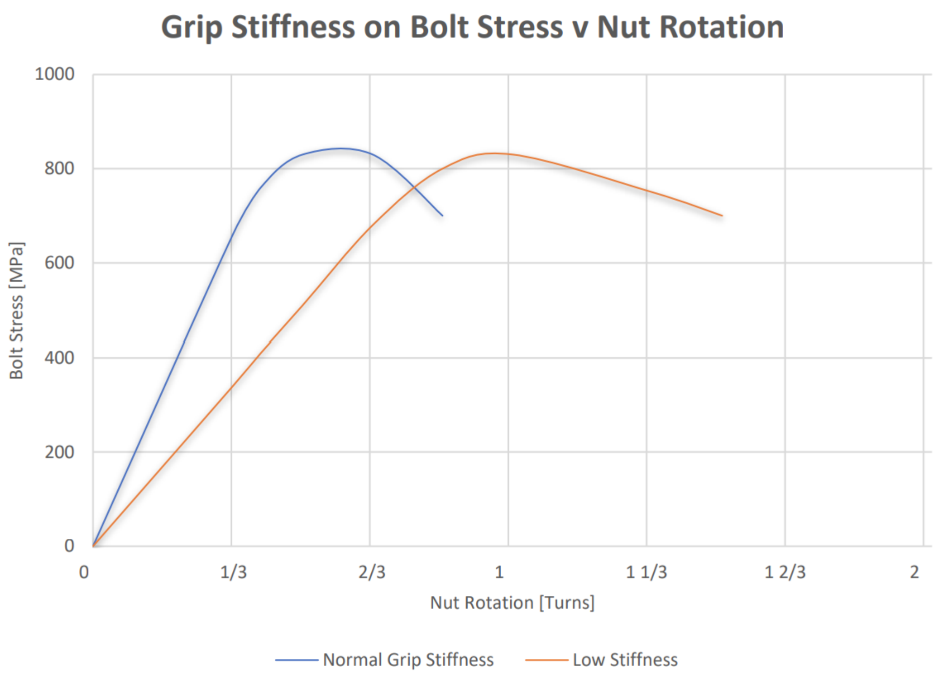


Figure 18 Effect of grip stiffness on tension developed in PC 8.8 bolt assembly

11.4 Treatment of gaps

Given the importance of ensuring gaps are minimised, AS/NZS 5131 Clause 8.2.1 provides guidance on the use of steel packer plates or shims. These shall be a minimum of 2mm thick and may need to be tapered. A maximum of three packer plates or shims shall be used.

Where steel packer plates or shims cannot successfully eliminate gaps, the alignment of the connected components may need to be corrected, for example by localised heating and forming to the correct alignment.

11.5 Tightening pattern

AS/NZS 5131 Clause 8.3 prescribes the snug tightening pattern as “Snug-tightening of the bolts in the connection should proceed systematically from the most rigid part of the connection towards the free edges. More than one cycle of snug-tightening may be required”.

Figure 19 indicates a typical snug tightening pattern based on the requirements of the Standard. Figure 20 identifies the most rigid part of a number of common connection types.

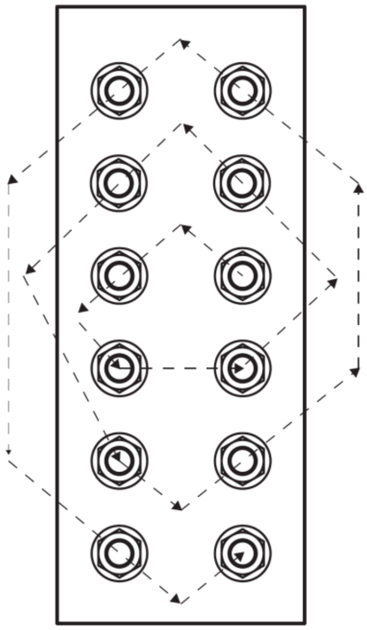


Figure 19 Typical snug tightening sequence

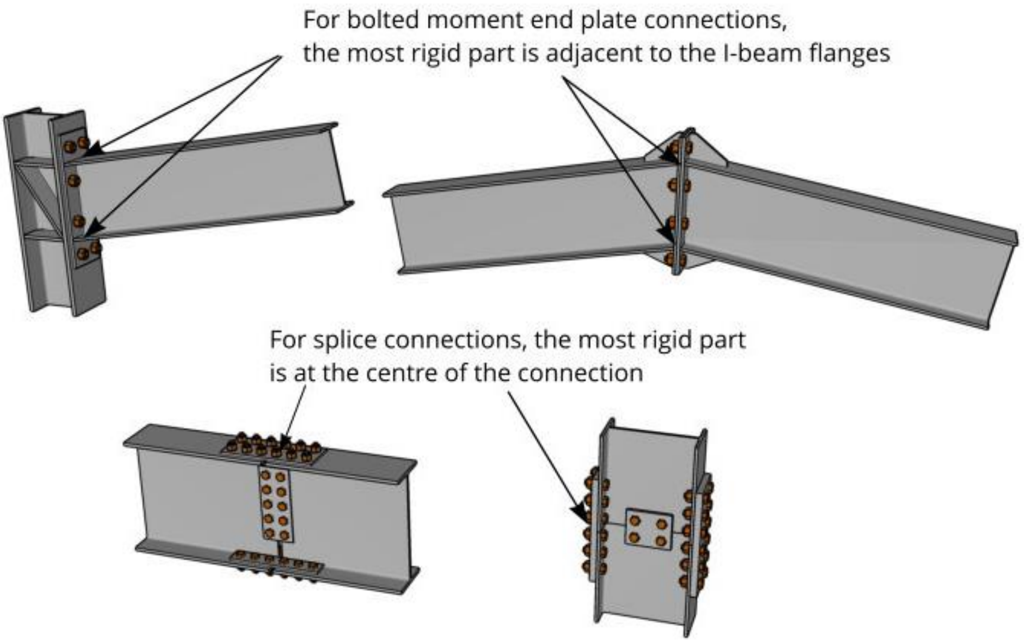


Figure 20 Rigidity location for connection types

12.0 TENSIONING OF HIGH STRENGTH BOLTED CONNECTIONS

12.1 Context

The requirements for tensioning of connections utilising high strength bolts (property classes 8.8 and 10.9) are defined in AS/NZS 5131 Clause 8.5 and may be summarised as:

- Tensioning shall only be undertaken by competent personnel
- Tensioning must only be undertaken after all bolts are snug tightened as previously described
- The tensioning pattern shall be as previously described for snug-tightening
- A minimum required bolt tension is prescribed for each size and property class of bolt assembly, as indicated in Table 4. Knowing the minimum bolt tension, and hence clamping force, the engineer can use the friction coefficient between the connected plies to calculate the frictional resistance of the connection interface
- Three methods for achieving the required bolt tension are referenced:
    - The part-turn method of tensioning
    - The direct-tension device method of tensioning
    - Use of specialised fasteners and fastening methods

To provide a technical context for high strength bolt tensioning, it is important to understand the behavioural assumptions on which the tensioning methods are predicated, in particular the part-turn method discussed subsequently. Appendix A provides a background to high-strength bolt behaviour during tensioning.

Table 4 Minimum bolt tensions

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

12.2 Part-turn method of tensioning

The part-turn method of tensioning relies on a relationship between the turn of the nut (or bolt head) and the tension developed across the grip of the bolt, assuming the grip comprises solid steel elements (plates or packers).

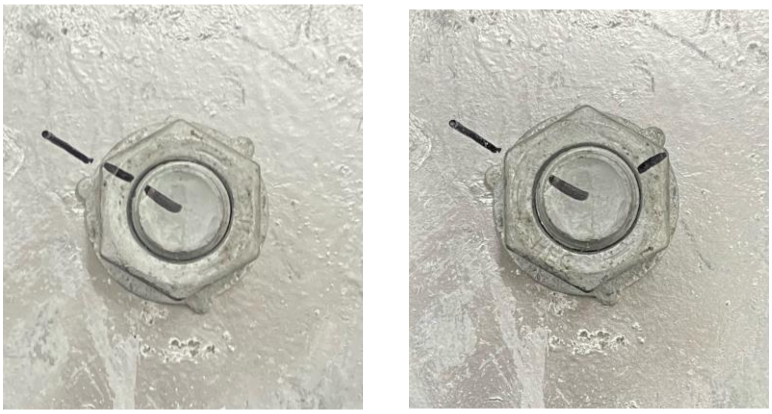
The process defined in AS/NZS 5131 Clause 8.5.6 comprises:

- With the bolt assemblies snug tightened, apply location marks to mark the relative positions of the bolt and nut prior to application of the part-turn. Although it is not required that the location marks are permanent (unless stated in the construction specification), the use of permanent location marks will aid in subsequent inspection. Location marks should not be applied only to the nut and connection ply, as this does not necessarily measure relative location of the nut compared to the bolt if the non-rotated part slips during tensioning. Figure 21 indicates appropriate location marking, at snug tight (Fig 21(a)) and after tensioned (Fig

21(b)). Figure 22 shows location marking that is not appropriate, being not clear or prone to error.

Marking of the ply as well as the bolt end and nut is important, because it indicates if the bolt head has inadvertently rotated

- Rotate the nut by the amount prescribed in Table 8.5.6 of AS/NZS 5131, whilst holding the bolt head in position. If the nut cannot be rotated, the bolt head may be rotated whilst the nut is held, provided a washer is located under the bolt head
- For bolt lengths exceeding those given in Table 8.5.6 of AS/NZS 5131, a suitable test shall be utilised to establish the required amount of rotation necessary to obtain the required bolt tension. Note that a simple elastic assessment (PL/EA) will not provide an accurate required extension / part-turn due to thread deformation and other factors
- Where one or both of the ply faces bearing against the bolt head or nut are sloping, Table 8.5.6 of AS/NZS 5131 does provide modifications to the degree of part-turn to accommodate this. However, every effort should be made to correctly align the faces to avoid placing additional bending in the bolt, in particular for 10.9 bolts with higher loads and less ductility



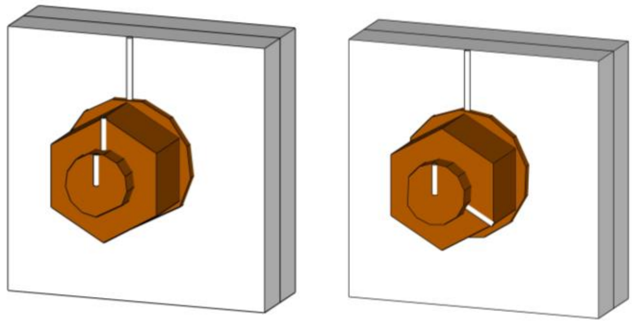
(a) (b)

Figure 21 Correct location marking of bolt assemblies

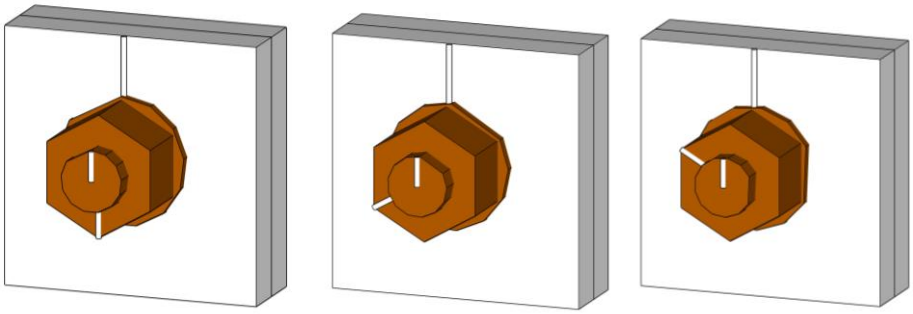
(a) (b)

Figure 22 Incorrect or unclear location marking of bolt assemblies

Figure 23 shows a bolt assembly clearly marked, with matching location lines starting from the centre of the bolt and extending across the nut face and onto the surface of the fitment. Different amounts of part-turn are also shown.



(a) Marking at snug tight (b) Marking at 120 deg turn



(c) Marking at 180 deg turn (d) Marking at 240 deg turn (e) Marking at 300 deg turn

Figure 23 Clear location marking of bolt assembly

It must be noted that Clause 8.5.5 of AS/NZS 5131 states "The part-turn method of tensioning shall not be utilized for Grade 10.9 bolts unless the suitability of the method to develop the minimum bolt tension specified in Table 8.5.5 has been ascertained by appropriate application of the procedure in Clause 8.5.7(a)".

12.3 Direct-tension indicator method of tensioning

Direct-tension indicators (DTI's) are, in effect, single use load cells which directly measure tension in the bolt assembly. The most common types are 'compressible washer type' DTI's. Examples are shown in Figure 24. In Figure 24(a), the protrusions on the washer are flattened under application of the prescribed compression from the tension in the bolt. A feeler gauge is used to measure the gap and tensioning is complete when the assessed gap is sufficiently small. Figure 24(b) shows a variation, colloquially termed a 'squirter washer'. The void under the protrusions is filled with a high visibility elastomer compound which squirts out channels in the washer when the protrusions have been sufficiently compressed, as shown in Figure 24(c).

The process defined in AS/NZS 5131 Clauses 8.5.7 and 8.5.8 comprises:

- Confirm the suitability of the DTI's: by testing a representative sample of not less than three bolts for each diameter times bolt length combination and for each grade of bolt to be used. The bolt assemblies used for testing must be taken from the same assembly lot as used for the works. Appendix C of this document provides further details on 'pre-installation verification testing'
- Assemble the DTI's onto the bolt assembly as recommended by the manufacturer. It is important that a compressible washer type DTI is positioned correctly to ensure correct operation, as shown in Figure 25. The DTI must be placed under the part that is not rotated (bolt head or nut)
- Ensure all bolts are snug tight

(a) (b)

(c) Squirter washer implementation

Figure 24 Example compressible washer type DTI's

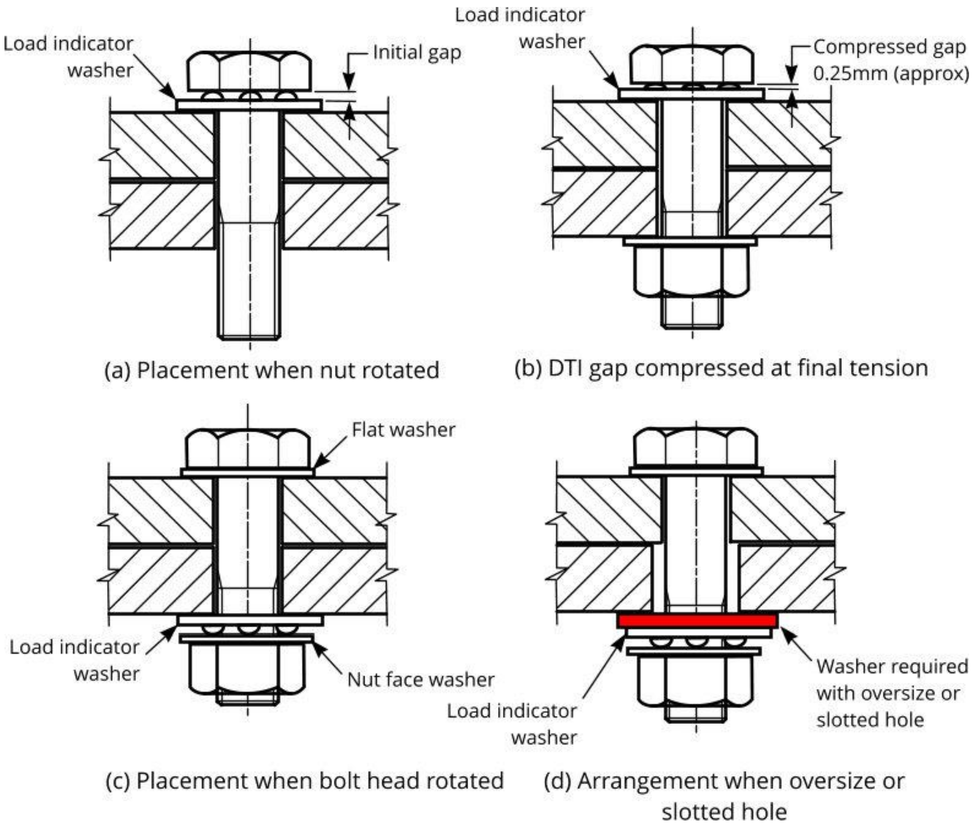


Figure 25 Correct placement of compressible washer type DTI's

- Rotate the nut (or bolt head) until the DTI indicates the required tension has been obtained. The specific process and measurements required must be in accordance with the manufacturer's specification. A feeler gauge may be used to confirm the correct compression has been reached.

12.4 Aspects of DTI use

Over-compression of DTI's

There will be times when the DTI's are compressed to significantly less than the gap required for indication of the minimum tension being achieved, including nil gap. This is an indication of over-tensioning and should be discouraged.

However, in general, a nil or smaller than required gap should not be cause for rejection. Compliant property class 8.8 structural bolts do have sufficient ductility to withstand a reasonable degree of over-tensioning. However, more care is required with property class 10.9 structural bolts. If there is a question as to whether the bolts have deformed excessively under the tension applied, a representative sample could be removed and inspected for deformation by running the nut down the bolt threads to the runout. If the nut runs down the threads there is no excessive deformation.

Note however that <u>any bolt that has been tensioned cannot be reused</u>.

Galvanizing of DTI's

If DTI's are required to be galvanized, this should be done by the manufacturer prior to delivery. Galvanizing of the DTI post-delivery can affect the performance of the washer.

12.5 Torque controlled tensioning (Use of specialised fasteners and fastening methods)

Torque-controlled methods of tensioning rely on a defined relationship between the torque applied to the nut (or bolt head) and the tension that is developed in the bolt assembly, as indicated in Figure 26. Torque applied to the nut is converted to tension in the bolt shank via the movement of the nut against the bolt threads and therefore the torque-tension relationship is highly dependent on the friction between the nut and bolt threads.

The 'k' factor can vary significantly depending on material and surface condition

Surface treatment (to nut and bolt)	'k' factor
Plain (as received)	0.2
Hot-dip galvanized – clean and dry	0.22
Graphite coatings	0.19
Rusty – exposed outdoors 2 weeks	0.30
Machine oil	0.21
Phosphate and oil	0.19
Zinc plate	0.33
Molydisulfide grease	0.14

$$M = k \cdot d \cdot F$$

The 'k' factor is largely influenced by:

- condition of the bearing surfaces (threads and nut bearing face
- type of finish/coating

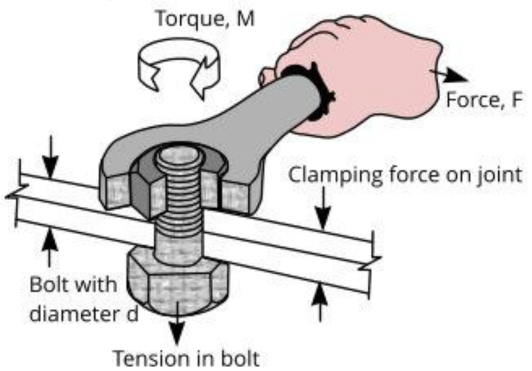


Figure 26 Torque-tension relationship for torque-controlled tensioning

Clause 8.7 of AS/NZS 5131 references use of specialised fasteners and fastening methods. It does not specifically mention torque-controlled methods of tensioning, but nevertheless is designed to allow any specialised fastening method.

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.

AS/NZS 1252.1 defines a relationship between torque applied to the nut (or bolt) and the tension developed in the bolt assembly given by:

$$M_{r,i} = k_m \, d \, F_{p,C}$$

where:

$M_{r,i}$ = torque required to develop minimum bolt tension $F_{p,C}$

k_m = k_m for k-class K1 or K2 as appropriate, also known as ‘nut factor’

d = nominal diameter of the bolt

$F_{p,C}$ = minimum bolt tension (preload) defined in the relevant Standard

The value of k_m for the so-called ‘k-class’ of K1 or K2 is established by the ‘extended assembly test’ outlined in Appendix D of AS/NZS 1252.1. Bolt assemblies for which this testing has not been undertaken and therefore cannot reliably be used for torque-controlled methods of tensioning are termed k-class K0. K0 bolts cannot be used for torque-controlled tensioning but K1 or K2 assemblies can be used in a K0 application, utilising the K0 installation methodology.

The usual high strength structural bolts supplied in Australia have historically been effectively k-class K0. The difference between k-class K1 and K2 lies in the tighter control over the variability of the k-value with k-class K2.

When using torque as a measure of tension in the bolt assembly, the following installation procedure is recommended:

- Ensure the equipment used for application of the torque, typically a torque wrench, is in good condition and calibrated correctly. The calibration should be current. The wrench should be recalibrated for any changes in bolt, nut or washer surface condition or when any major part of the wrench or supply lines is changed.
- Ensure personnel are competent and trained in the use of the particular equipment
- Confirm bolting assemblies are properly identified, packaged and fit-for-purpose.
- Establish the ‘nut factor’ (k_m) from the packaging and hence the torque necessary to provide the required tension on the bolt assembly
- Undertake ‘pre-installation verification testing’. Refer Appendix C.
- Bring all bolts to the snug tight condition
- Tension each bolt in the connection in the pattern defined in AS/NZS 5131 to the torque calculated to provide the minimum required tension in the bolt assembly

EN 1090-2 (Ref. 16) provides clear direction on installation using torque.

12.6 Tension control bolts (Use of specialised fasteners and fastening methods)

Clause 8.7 of AS/NZS 5131 references use of specialised fasteners and fastening methods, including tension control bolts (TCB’s). The requirements are:

- Installation shall be by competent personnel, trained by the TCB supplier
- Installation shall be in accordance with the manufacturer specification

As shown in Figure 27, TCB's typically comprise a high strength bolt with a specially formed splined tail which includes a necked area designed to break under application of a defined level of torque which corresponds to the minimum tension required in the bolt. As shown in Figure 28, the wrench used to tension the TCB's grips the splined end. Nut rotation is reacted against the splined end, which breaks off when the required torque has been reached.

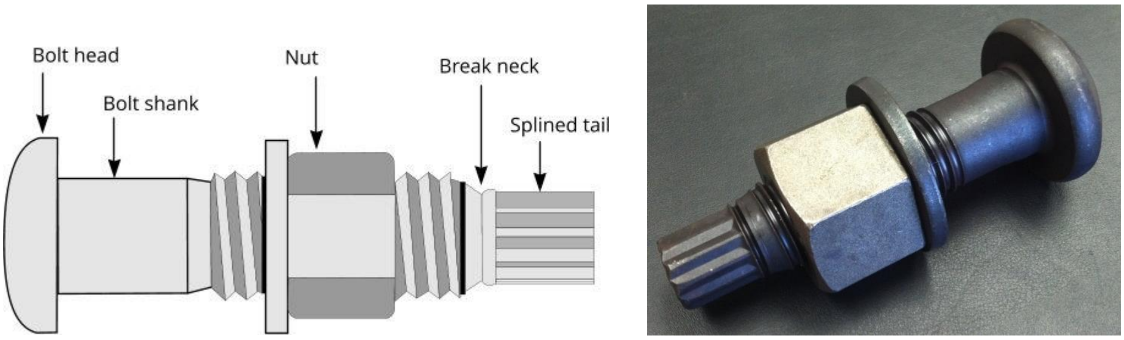


Figure 27 Typical Tension Control Bolt (TCB)

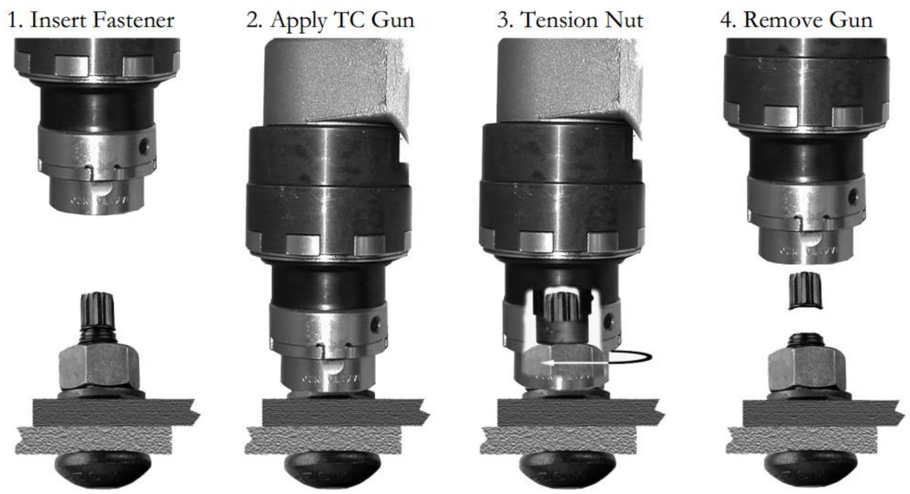


Figure 28 TCB wrench operation

TCB's are, in effect, a torque-controlled method of tensioning, in which the applied torque is automatically limited by breakage of the neck of the splined tail of the bolt. Therefore, the same controls on quality and the torque-tension relationship exist as for torque-controlled bolting.

When using tension control bolts, the following installation procedure is recommended:

- Ensure the equipment used for application of the torque, typically a torque wrench, is in good condition and working correctly
- Ensure personnel are competent and trained in the use of the particular equipment
- Confirm bolting assemblies are properly identified, packaged and fit-for-purpose.
- Undertake 'pre-installation verification testing'. Refer Appendix C.
- Bring all bolts to the snug tight condition
- Tension each bolt in the connection in the pattern defined in AS/NZS 5131 until the TCB's break at the neck

13.0 WEATHERING STEEL BOLT ASSEMBLIES

13.1 Context

Weathering steel bolt assemblies must be used when constructing structures utilising weathering steel plate to AS/NZS 3678 to ensure compatibility of aesthetic (similar corrosion patina) and minimise the potential for galvanic corrosion between dissimilar metals. In most respects weathering steel bolts are similar in performance to the equivalent high strength structural bolts to AS/NZS 1252.1. However, there are particular aspects that require attention, as noted below.

The New Zealand Weathering Steel Guide for Bridges (Ref. 27) and Bluescope Weathering Steel Design Guide for Bridges in Australia (Ref. 28) provide definitive guidance on application of weathering steel. Section 3.5 of Ref. 28 provides specific guidance in relation to bolted connections.

13.2 Specification

Clause 5.5.6 of AS/NZS 5131 provides guidance on specification of weathering steel bolts and states:

"Weathering steel assemblies shall be made of steel with improved atmospheric corrosion resistance, the chemical composition of which shall be as specified in AS/NZS 3678 or AS/NZS 1594".

It is also noted that "Type 3 Grade A fasteners to ASTM A325 would be suitable".

ASTM A325/M Grade A Type 3 fasteners are currently being imported into Australia.

ASTM A325 (Ref. 17) includes specification of both imperial and metric bolts. The */M* designation refers to metric bolts. The bolt diameters covered range from M16 to M36 inclusive.

The *type* refers to the type of material used to make the bolt. Type 3 is weathering steel.

Grade A refers to the specific chemical composition, termed 'Composition A' in ASTM A325/M, but commonly referenced as 'Grade A' in specifications. Grade A is appropriate for weathering steel structural plate product manufactured in Australia to AS/NZS 3678.

It is important to understand that suitable fasteners to other Standards are not precluded but should be subject to the same considerations as listed below.

13.3 Identification and traceability

As with conventional high strength structural steel bolts, weathering steel bolts must meet similar requirements for identification and traceability. Figure 29 illustrates typical bolt head identification and packaging label.

(a) Bolt head marking (b) Package labelling

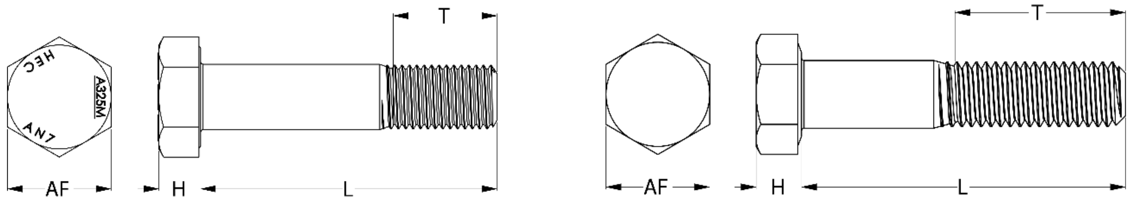
Figure 29 Example bolt head marking and package labelling for weathering steel bolt assemblies

13.4 Metric versus imperial

ASTM A325 has specification for both imperial and metric threads. It is important that supply of bolts is confirmed during the design phase of the project. Changing hole sizes and spacing in steelwork is a costly exercise and can be avoided by confirming supply early in the project. Metric weathering steel bolts are now being imported for Australia and New Zealand and are preferred to imperial bolts due to familiarity, cohesion with current design standards and the availability of tooling.

13.5 Thread lengths

ASTM A325/M bolts have considerably shorter thread lengths when compared with AS/NZS 1252.1, as shown in Figure 30. Shorter thread lengths give more opportunity for designers to detail connections with the shear plane crossing the unthreaded shank, thereby utilising the higher shear capacity of the unthreaded shank. However, designers should be aware that tolerance for steel thickness and fit may need to be considered in more detail when using weathering steel bolts.



(a) ASTM A325/M thread length (b) AS/NZS 1252.1 thread length

Figure 30 Threaded length comparison of bolts to ASTM A325/M bolts versus AS/NZS 1252.1

13.6 Handling on site

Weathering steel bolts will begin forming the red patina shortly after being exposed to the environment. It is important that bolts are suitably stored and tensioned shortly after fit up as the patina will increase friction between the bolt and nut threads and markedly increase the torque required to fully tension the assembly. This is true for all structural bolt assemblies but is greatly amplified with the use of weathering steel. Figure 31 shows examples of incorrect handling of weathering steel bolts on site. Corroded bolts are present in connections to be tensioned and bolt components are shown on the ground exposed to the environment instead of in boxes.

Where it is found that weathering steel bolts have corroded and cannot be tensioned correctly, they may be able to be removed, cleaned and re-lubricated with wax in order to allow successful tensioning. However, the manufacturer or supplier must be consulted for specific guidance on this and the method of cleaning and lubrication. Representative samples of the bolt assemblies must also be subjected to pre-installation verification testing.

Given the issues noted above, it is highly recommended that all weathering steel bolt assemblies (excluding specifically manufactured tension-control bolts)) are tensioned using the part-turn method, which does not rely on a known torque-tension relationship. Note however that the part-turn method can still result in bolt breakages during tensioning if the bolt assemblies are not in good condition.

To address some of the issues noted above, in particular where it is expected that bolted connections may be exposed to the weather for significant periods prior to tensioning, it may be appropriate to utilise conventional high strength structural bolts initially to assemble the connections and ensure alignment of the structure, and swap these out for weathering steel bolts immediately prior to the planned final snug tightening and tensioning of the bolted connections. This also reduces the risk of damage to the more costly weathering steel bolts during erection.

Figure 31 Weathering steel bolts unable to be tensioned due to poor site handling practice

13.7 Pre-loading suitability

Unlike AS/NZ 1252.1 and EN 14399, ASTM A325/M does not require the establishment of an assembly lot and components (bolt, nut, washer) may be supplied from more than one manufacturer. Under this scenario, in order to assure performance of the bolt assembly, American fabrication and erection standards require pre-installation verification to be performed for all bolt tensioning methods prior to installation.

However, AS/NZS 5131 does not have the requirement for pre-installation verification for the part-turn method of tensioning, on the basis that the bolt assemblies to AS/NZS 1252.1 are required to be supplied as an assembly, which has undergone assembly testing as part of manufacturing quality control.

It is therefore important that if purchasers are specifying ASTM A325/M bolt assemblies, they also specify ASTM F3125 Annex A2 – Rotational Capacity Test (on the purchase order) to be performed on the supplied bolt assemblies. This ensures that bolt assemblies supplied are fit for tensioning and brings weathering steel bolts supplied to the ASTM standard in line with the intent of Australian and New Zealand requirements for structural bolts.

If bolt assemblies have been supplied without evidence of the ASTM F3125 Annex A2 – Rotational Capacity Test, then the bolt assemblies must undergo pre-installation verification testing.

14.0 WHY DO BOLTS BREAK DURING INSTALLATION?

There are four primary failure modes of bolts that might be experienced during tensioning of high strength bolts. The modes and likely causes are:

- Torque failure
  - Incorrect or no lubrication
  - Poor storage and handling (corrosion)
  - ‘galling’ of nut on bolt
- Tension failure
  - Over tightening
  - Non-compliant (poor quality) material
  - Poor heat treatment
- Thread stripping
  - Incorrect (non-compliant) tolerances
  - Poor heat treatment
- Bolt head breakage
  - Incorrect material or heat treatment
  - Incorrect geometry

The mode of failure is an important indicator of the root cause and therefore an important diagnostic tool when problems are experienced on site. Appendix B provides more detail on each of these failure modes and causes.

15.0 SITE INSPECTION OF BOLTED CONNECTIONS

The requirements for site inspection of bolted connections are defined in AS/NZS 5131 Clause 13.7 ‘Inspection of mechanical fastening’. For all connection types, the significant aspects include:

- An Inspection and Test Plan (ITP) is required (refer next section)
- Inspection must be undertaken by a competent person
- The results of all inspections must be documented in an Inspection Report
- Documentation, packaging and marking of bolting components must be inspected
- Prior to installation, bolting components shall be visually inspected for damage, surface condition etc
- All contact surfaces shall be inspected prior to assembly of connections
- All connections shall be inspected after snug tightening of the bolts, including specifically:
  - All bolts correctly in position and of correct grade and size
  - All plies are the correct thickness and dimensions
  - Firm contact has been achieved, with correct packing where required
  - Visual checking that all bolts have been tightened sufficiently to prevent turning of the nut without the use of a spanner. Physical checks to be undertaken where this cannot be established visually

In addition, for tensioned high strength bolted connections, the checks shall include:

- Periodic observation of tensioning during installation to confirm proper procedures are being employed
- After tensioning, inspection of the connections to confirm the correct tension has been applied. In the case of part-turn method, observation of the match-marking. In the case of the DTI method, inspection procedures defined by the manufacturer.

AS/NZS 5131 requires that the inspection sampling is undertaken in accordance with a sampling plan, the requirements of which are defined in the Standard.

Although not specifically noted in AS/NZS 5131, it is recommended that the pre-installation verification is also inspected.

16.0 INSPECTION AND TEST PLAN (ITP) FOR BOLTED CONNECTION INSTALLATION

AS/NZS 5131 Clause 13.7.1 requires an Inspection and Test Plan (ITP) for all Construction Categories except CC1. The contents of the ITP must include:

- Identification and documentation (including traceability)
- Tightness of snug-tight bolts
- Preparation of contact surfaces
- Installation of packing, if required
- Tension in tensioned high strength bolts
- Any special requirements of the construction specification

The ITP is to nominate who is to carry out the inspections, the stages at which the inspections are to be carried out and the bolted connections to be inspected.

An example ITP for bolted connections is included in Appendix D.

ASI Tech Note TN011 (Ref. 21) provides engineers with guidance on implementing the requirements of AS/NZS 5131, including ‘construction categories’.

17.0 TESTING OF HIGH STRENGTH BOLT ASSEMBLIES

17.1 Context

Pre-installation verification is intended to help ensure bolt assemblies used on projects are fit-for-purpose at the point of installation. However, where pre-installation verification has not been undertaken, problems may arise that require specific testing.

Issues experienced with installation of high strength bolts, in particular tensioning, are not always straightforward to diagnose. In some cases, installation process is to blame and can relatively quickly be addressed through on-the-job training of bolting personnel and supervisors. In this case bolt suppliers can usually provide support and/or direction as to appropriate training providers. It is therefore important that structural bolt assemblies are sourced from quality suppliers with adequate support resources.

However, invariably there are situations where bolt assembly compliance may be in question and testing of bolt assemblies may be required to establish bolt assembly performance and/or resolve disputes.

In addition to the required testing of the bolt components and assembly undertaken by the manufacturer and defined in AS/NZS 1252.1, there are two additional opportunities for testing of bolts currently available in the Australian marketplace:

- Supplier testing prior to sale

- Project-specific bespoke testing

17.2 Supplier testing prior to sale

Recognising the difficulty that stakeholders have been experiencing with properly assessing product conformity of bolt assemblies to AS/NZS 1252.1, the ME-029 Standards committee decided that a Part 2 document was required, defining a formalised testing regime that is intended to be undertaken before the product is first put on the market in Australia. It was expected that in most cases the testing regime would be managed by the bolt importers, utilising either their own accredited labs or accredited third-party testing facilities.

AS/NZS 1252.2 provides definition of:

- Processes for selection of the correct type and range of samples to be tested
- The specific testing required for each of the critical product characteristics
- The credentials of testing laboratories utilised
- Review of the outcomes of the testing regime
- The form and extent of reporting
- The attestation of conformity, in the form of a Supplier Declaration of Conformity (SDoC)

It is important to note that Part 2 is not called up or mentioned in Part 1, but rather must be separately and optionally called up by the procurer/specifier to ensure that bolt assemblies are verified. **It is ASI's strong recommendation that all engineers/specifiers/procurers should call up high strength bolt assemblies to AS/NZS 1252.1, with verification testing to AS/NZS 1252.2.** The ASI National Structural Steelwork Specification (Ref. 18) and 'Standard Drawing Notes' (Ref. 19) provides suitable wording.

All product to AS/NZS 1252.1 should be sold with verification testing to AS/NZS 1252.2. Where testing to AS/NZS 1252.2 cannot be demonstrated, the quality of that supply must be questioned and alternative demonstrably compliant supply should be sourced. However, if this is not possible, then ASI strongly recommends that procurers require suppliers to demonstrate product compliance utilising the testing regime described in Appendix I of ASI Tech Note TN001 (Ref. 5).

17.3 Project-specific bespoke testing

Bespoke testing may be required to address project-specific issues that arise. In this case, the testing that is required may be selected from the range of tests prescribed in Appendix I of ASI Tech Note TN001. The extent of testing may depend on the exact nature of the problems identified.

The single most important test described in Appendix I of TN001 is the 'basic assembly test', which should be undertaken as a minimum.

The 'basic assembly test', and also the 'extended assembly test' which must be used where a torque-tension relationship is required, are described in more detail in ASI Tech Note TN001.

18.0 STAKEHOLDER RESPONSIBILITIES

Australian Standards do not in general assign responsibilities, considering these to be contractual. However, as distinct from the contractual structure of the project, Workplace Health and Safety Regulation is overarching on all construction projects in Australia and defines a 'duty of care' responsibility for all stakeholders, to ensure, so far as is reasonably practical, risk minimised outcomes. Clearly, training, competency and following established industry standards and processes are all components of minimising risk and being able to demonstrate duty of care.

Appendix E defines a rational and defendable accepted practice process for installation of bolt assemblies, in particular tensioned high strength bolt assemblies. A recommended division of stakeholder responsibilities consistent with that process is also defined, referenced back to the sections in this Tech Note.

19.0 CONCLUSION

There have been demonstrable issues with the quality, compliance and installation of structural bolt assemblies in Australia over the past years. The 2016 revision of AS/NZS 1252 was specifically designed to facilitate improved compliance outcomes for high strength bolts for the Australian marketplace. ASI Tech Note TN001 provides guidance to industry on the quality and compliance of structural bolt assemblies for the Australian market.

The installation issues experienced in the market are a result of a combination of poor-quality bolt assemblies and poor or ill-informed installation practice. Tensioning of high strength structural bolt assemblies is a 'special process' and requires particular attention for successful and verifiable outcomes. That attention starts with ensuring procurement of compliant bolt assemblies and includes following a defined process for assembly, snug tightening and, if required, tensioning of the bolt assemblies.

This current Tech Note TN016 provides engineers, bolt installers and other relevant stakeholders with a defined procedure and responsibilities to help ensure successful outcomes. It also forms a rational basis for bolting supervisors and structural engineers to understand the behavioural aspects of bolted connections and provide informed guidance to bolting crews and the builder where problems are experienced.

20.0 ACKNOWLEDGEMENTS

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- Keays Engineering
- R.I.BROWN Pty Ltd
- SOTO Consulting Engineers
- WGA

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APPENDIX A

HIGH-STRENGTH BOLT BEHAVIOUR DURING TENSIONING

A.1 Context

An understanding of the behaviour of high-strength bolts during tensioning is fundamental to addressing issues that may arise during tensioning of the bolt assemblies, and also underscores an understanding of the basis of the requirements defined in our Standards.

A.2 Bolt Assembly Load-Elongation Behaviour during Tensioning

Figure A.1 indicates a typical generic load-elongation graph for a bolt assembly tensioned by the part-turn method, in this case for a property class 8.8 bolt assembly. Typical actual measured outcomes on each bolt of the bolt group are also indicated on the graph below the horizontal axis.

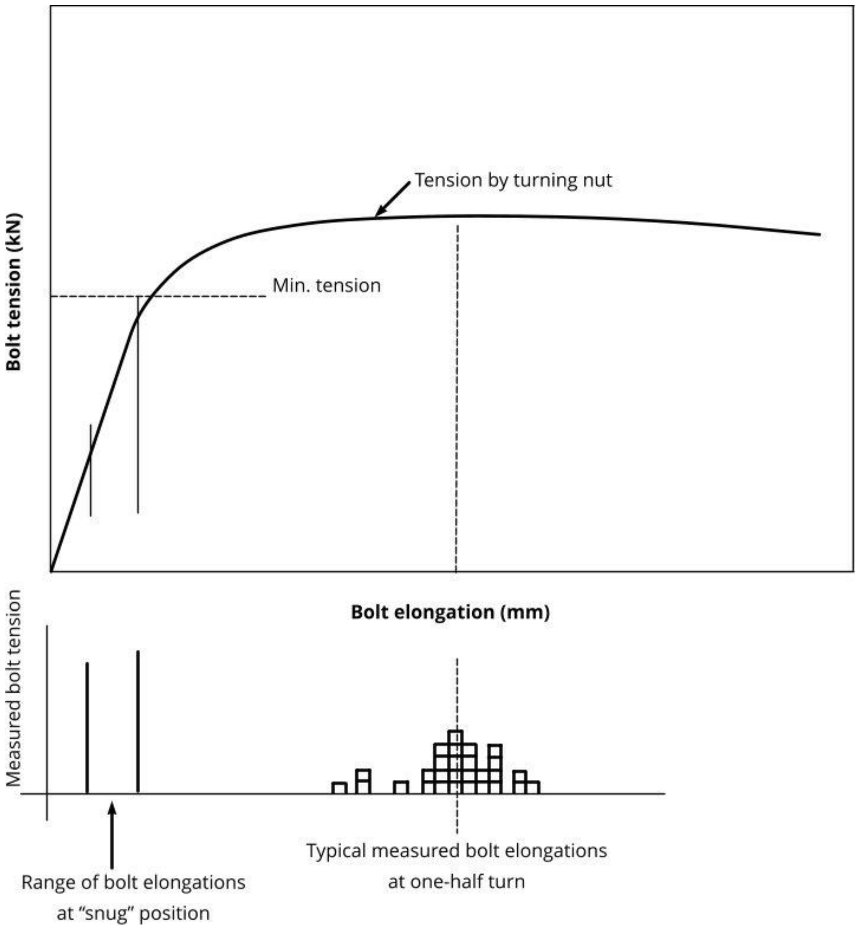


Figure A.1 Load versus elongation behaviour of bolt assembly during tensioning
(modified from Ref. 22)

The important points to note include:

1. Whilst there is a range of actual bolt elongations (and tensions) induced by the variability of the snug tightening process, these bolt tensions typically fall within the elastic range of bolt behaviour. Therefore, snug tightened bolts can be taken out and re-used.
2. Taking, for example, one-half turn as the required part-turn rotation (as specified in Table 8.5.6 of AS/NZS 5131 based on a bolt length between four and eight diameters), there is a corresponding variability in the total bolt elongation at one-half turn. However,

due to flatness of the curve in the nonlinear range, there is very little difference in the corresponding actual bolt tension.

3. In all cases, the bolt tension is comfortably above the minimum required tension specified for that bolt size in Table 15.2.2.2 of AS 4100 (and Table 8.5.5 of AS/NZS 5131).
4. The nonlinear load-elongation response of the high strength bolts when the required part-turn has been applied means that the final bolt tension achieved is relatively insensitive to the degree of snug tightness applied (within the range usually applied by an installer using a standard podger spanner or a properly operated rattle gun).

A.3 Non-linear Bolt Response

High-strength structural bolts intended for tensioning are designed to yield under the application of the required tension through tightening of the nut. The yielding occurs predominantly in the threaded zone of the bolt within the grip, that is, the length between the nut face and unthreaded portion of the shank, indicated as ‘grip thread zone’ in Figure A.2. The threaded tensile area is approximately 80% of the area of the unthreaded shank.

For this reason, as specified in Clause 8.5.4 of AS/NZS 5131, high-strength structural bolts should be tightened once only and never reused after being loosened.

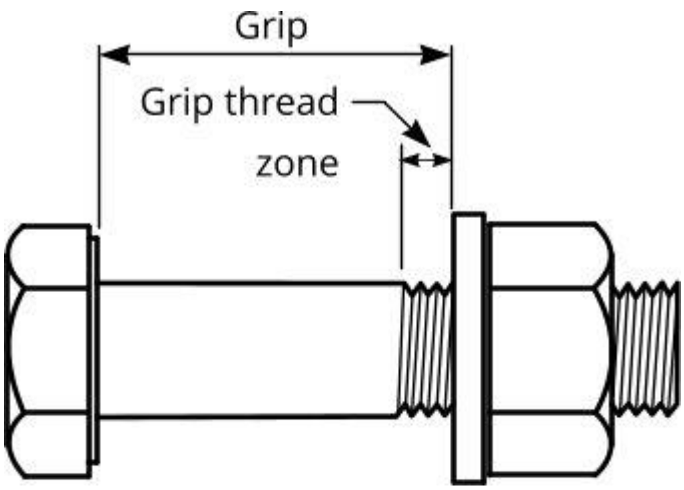


Figure A.2 Grip thread zone

A.4 Behaviour of Property Class 8.8 versus 10.9 Bolt Assemblies

Figure A.3 shows a graph of bolt tension versus part-turn of nut from snug tight for both property class 8.8 and 10.9 bolts.

The important points to note include:

1. Calibration tests of PC 8.8 bolts with grip lengths greater than 4 diameters have shown that ½ turn nut rotation produced consistent bolt tensions in the inelastic range. These tests also demonstrated a sufficient margin of safety against fracture by nut rotation. For bolts with short grip thread zone, they could sustain a further two additional ½ turns before failure. Bolts with long grip thread zones could sustain an additional three to five ½ turns before failure.
2. Similar tests on PC 10.9 indicated:

a. For the same ½ turn of nut, the PC 10.9 bolts provide an approximate 20% greater load than the PC 8.8 bolts, due to the increased strength of the PC 10.9 bolts. This is the reason that the same turn-of-nut rotations apply equally to PC 8.8 and 10.9 bolts but give the different required bolt tensions.

b. However, the higher bolt strength of PC 10.9 results in a small decrease in the nut rotation capacity as compared to the PC 8.8 bolts. The studies show that the factor of safety against twist-off failure for a bolt installed to ½ turn from snug is approximately 3.5 for PC8.8 bolts and about 2.5 for PC 10.9 bolts. Therefore, greater care (and better site controls) is required when installing PC 10.9 bolts.

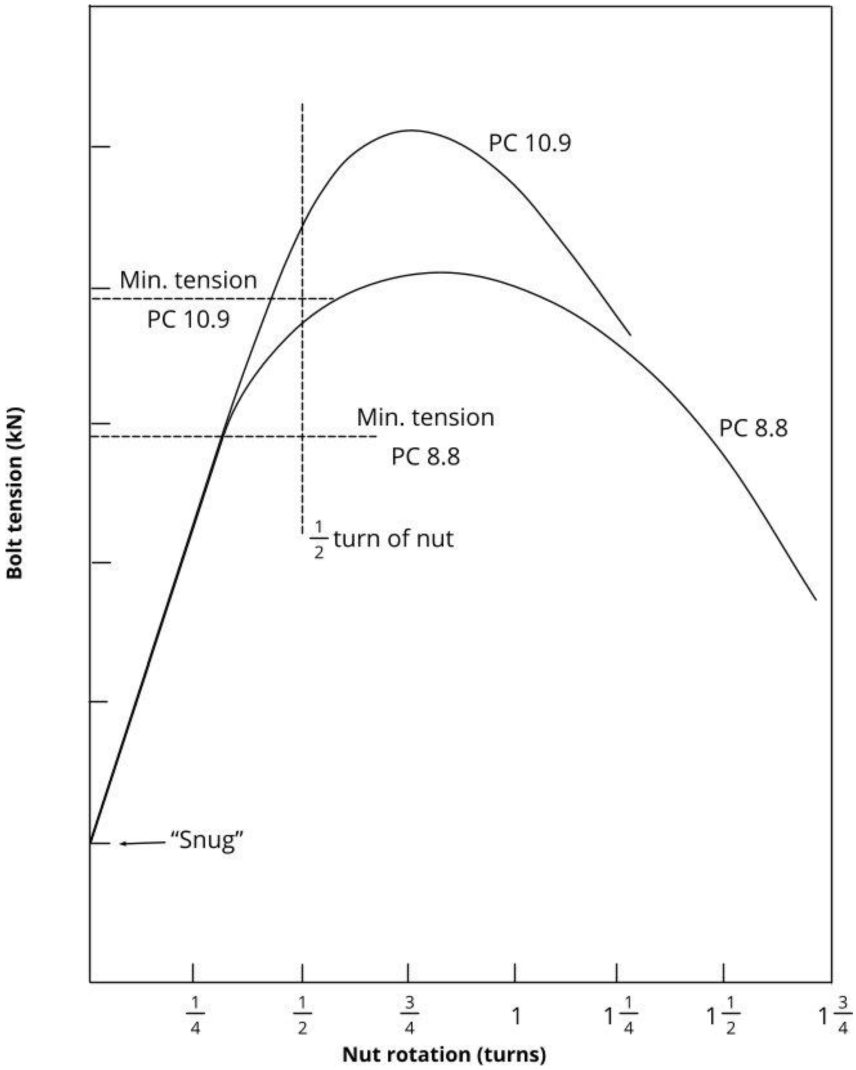


Figure A.3 Load versus part-turn for property class 8.8 and 10.9 bolts

The above data is interpreted from Ref. 22. For more detailed background and technical basis the reader is encouraged to review Ref. 22.

APPENDIX B

WHY DO BOLTS BREAK DURING INSTALLATION?

B.1 Context

Good quality compliant high strength bolting assemblies installed using the recommended installation procedures will rarely fail during installation. However, unfortunately, in the current procurement and site installation environment, failures are not uncommon.

To ensure safe risk minimised structures and duty of care under WHS Regulations, bolt breakages must be investigated, not ignored. The mode of failure is an important indicator of the root cause and therefore an important diagnostic tool when problems are experienced on site.

There are four primary failure modes of bolts that might be experienced during tensioning of high strength bolts. The modes are:

- Torque failure
- Tension failure
- Thread stripping
- Bolt head breakage

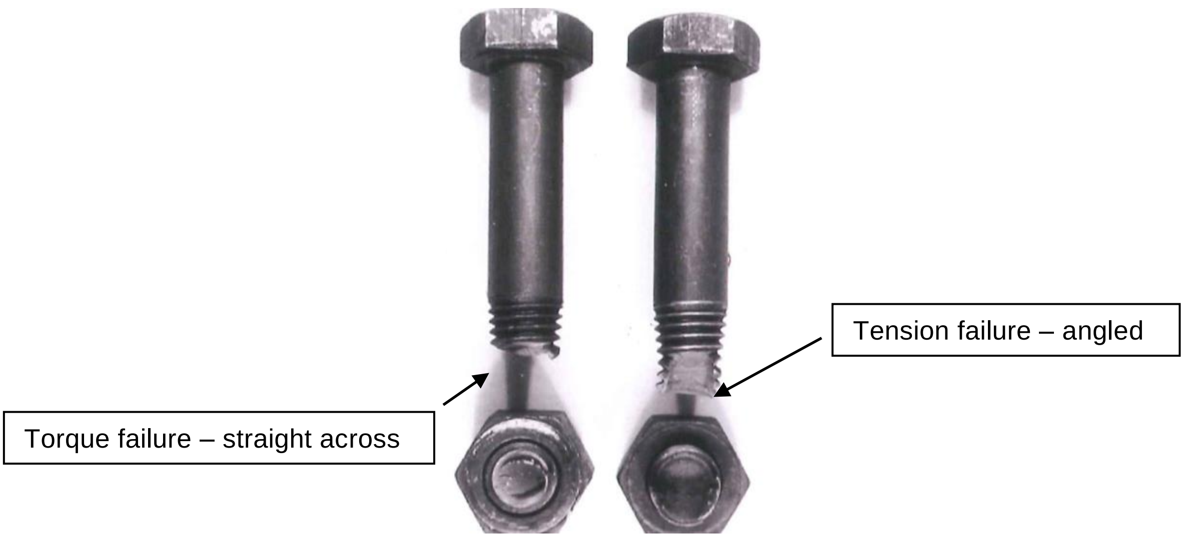


Figure B.1 Torque and tension failure mode surfaces

Figure B.1 illustrates the difference in bolt failure surface between a torque failure and a tension failure, which can be useful in a first stage identification of failure mode. Refer also to Sections B2 and B3 for more examples of the failure surfaces.

B.2 Torque failure

Torque failure, as illustrated in Figure B.2, is likely a consequence of one or other of:

- Incorrect or no lubrication
- Poor storage and handling
- ‘Galling’ of nut on bolt

Figure B.2 Torque failure

All of these causes affect (increase) the friction between the threads of the nut and bolt. Inadequate or no lubrication results in higher friction. Poor storage and handling can lead to corroded and/or dirty threads, increasing friction.

'Galling' or binding of the threads is a particular issue with galvanised bolts (the majority of structural bolts in the Australian market are galvanized). AS/NZS 1252.1 Clause 1.9.3 requires that the manufacturer ensure that nuts are galvanized before they are threaded. This ensures the threads are clear of galvanizing. Galling occurs when both the bolt and nut thread surfaces are galvanized or where excessive zinc is left on the bolt threads. Unfortunately, to save costs, manufacturers of low-quality bolting assemblies galvanize nuts after threading, increasing the chance of galling.

Higher friction between the bolt and nut threads means increased torque to obtain the same degree of part-turn of the nut or tension in the bolt using DTI's. Higher torque increases the risk of the bolt shank failing under torque during installation, as indicated in Figure B.3.

B.3 Tension failure

Tension failure, as illustrated in Figure B.4, is likely a consequence of one or other of:

- Over tightening
- Non-compliant (poor quality) material
- Poor heat treatment

Over tightening is indicative of poor installation practices and, often, use of untrained installation personnel. Site controls need to be put in place to ensure correct installation practices. As a minimum, a trained and experienced bolting supervisor should be responsible for all bolting crews.

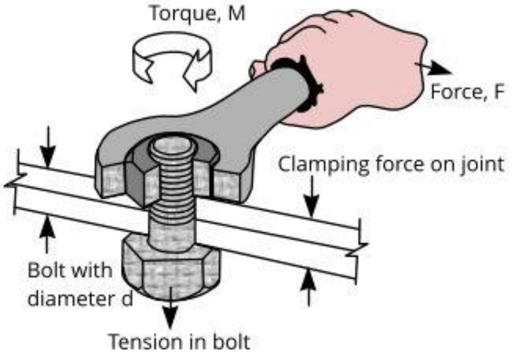
The 'k' factor can vary significantly depending on material and surface condition

Surface treatment (to nut and bolt)	'k' factor
Plain (as received)	0.2
Hot-dip galvanized – clean and dry	0.22
Graphite coatings	0.19
Rusty – exposed outdoors 2 weeks	0.30
Machine oil	0.21
Phosphate and oil	0.19
Zinc plate	0.33
Molydisulfide grease	0.14

$$M = k \, . \, d \, . \, F$$

The 'k' factor is largely influenced by:

- condition of the bearing surfaces (threads and nut bearing face
- type of finish/coating



When tightening a bolt, about 50-60% of the torque is used to overcome friction.
When k_m >0.25 the torque may fail the bolt.

Figure B.3 Typical k values

Non-compliant poor-quality material must be addressed through procurement practice, ensuring high strength bolt assemblies are compliant. ASI Tech Note TN001 (Ref. 5) provides detailed guidance on procurement practice in this regard.

Similarly, poor heat treatment is a function of manufacturing process and bolt assembly quality and must be addressed by controls on procurement practice.

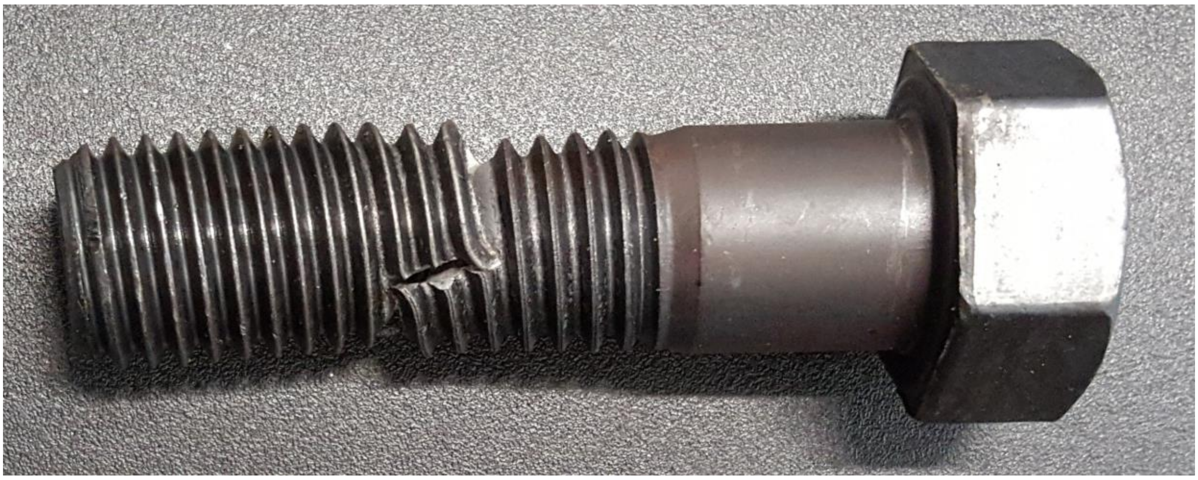


Figure B.4 Tension failure

B.4 Thread stripping

Thread stripping, as illustrated in Figure B.5, is likely a consequence of one or other of:

- Incorrect (non-compliant) tolerances
- Poor heat treatment

Figure B.5 Thread stripping failure

Both incorrect tolerances and poor heat treatment are a function of manufacturing process and bolt assembly quality and must be addressed by controls on procurement practice.

B.5 Bolt head breakage

Bolt head breakage, as illustrated in Figure B.6, is likely a consequence of one or other of:

- Incorrect material or heat treatment
- Incorrect geometry

Incorrect material or heat treatment and incorrect bolt geometry are a function of manufacturing process and bolt assembly quality and must be addressed by controls on procurement practice.

Figure B.6 Bolt head breakage
(from Queensland Department of Transport and Main Roads Specification MRTS78)

Bolt head breakage can also be caused by incorrect joint geometry, where the mating plies are not parallel. Shims should be used to avoid the bolt head bearing on one side only.

APPENDIX C

PRE-INSTALLATION VERIFICATION TESTING

C.1 Context

Good quality compliant high strength bolt assemblies installed using the recommended installation procedures will rarely fail during installation. However, unfortunately, in the current procurement and site installation environment, failures are not uncommon, due either to non-compliant bolt assemblies or incorrect installation practices.

Pre-installation verification testing is designed to:

- Test the particular batch of bolts received to ensure they are fit for purpose
- Ensure the installation crew is familiar with the correct installation procedure for the particular installation process to be used and the adequacy of the installation equipment

Pre-installation verification testing may also be used to determine the installation torque when using torque-controlled methods of tensioning when the bolt assemblies have been re-conditioned.

C.2 Scope

Pre-installation verification testing shall be undertaken for each lot of high-strength structural bolts received that are intended to be tensioned for /TB or /TF type connections.

A lot (number) is an alphanumeric code assigned by the manufacturer/distributor which identifies the manufacturer and the manufacturing lot number. Each diameter × length combination should have a separate lot number for traceability purposes.

Pre-installation verification should be undertaken immediately preceding installation of the particular lot of bolts.

C.3 Required testing

A representative sample of not fewer than three complete bolt assemblies of each lot to be used in the work shall be checked at the site of installation in a tension calibrator to verify that the selected tensioning method develops a tension that is equal to or greater than 1.05 times the minimum tension values specified in Table 8.5.5 of AS/NZS 5131. Washers shall be used in the pre-installation verification assemblies as required in the work.

Note: The requirement to attain 1.05 times the required minimum tension values recognises the inherent variability of the tensioning process and condition of the bolt assemblies

If the actual tension developed in any of the tested bolt assemblies is less than the value noted above, the cause(s) shall be determined and resolved before the lot of bolt assemblies are installed in the work. If cleaning and re-conditioning of the bolt assemblies does not correct the issue, the lot shall not be used for application in tensioned connections.

Note: TCB's must be returned to the manufacturer for re-conditioning

C.4 Tension calibrator

A 'tension calibrator' is a device that indicates the tension that is developed in a bolt. The tension calibrator used may be one or other of:

- **Hydraulic tension calibrator**: which measures hydraulic fluid pressure between two steel plates in the bolt grip. Because hydraulic tension calibrators undergo a slight deformation during bolt tensioning, the nut rotation corresponding to a given tension reading may be slightly higher than if the same bolt was tensioned in a solid steel assembly (in other words, for the same nut rotation, the tension reading will be slightly lower). An example of a hydraulic tension calibrator is the Skidmore Wilhelm bolt tester shown in Figure C.1.

- **Verified DTI**: Direct tension indicators (DTI's) may be used as tension calibrators, except for the part turn method of tensioning, because the deformation of the DTI consumes a portion of the turns provided. DTI's used as 'verified DTI's' must undergo a verification process as described below.

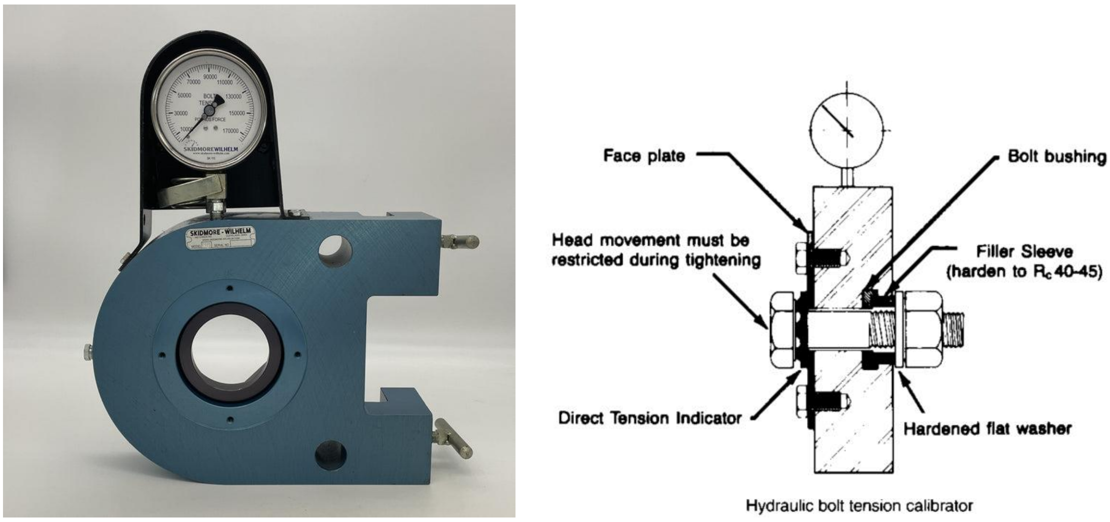


Figure C.1 Skidmore Wilhelm bolt tester

C.5 Verification of DTI's

A lot of DTI's to be used as 'verification DTI's' for the purposes of tension calibration of bolt assemblies must undergo a verification process.

The verification process comprises:

- A representative DTI is selected from the DTI lot to be used as 'verification DTI's'
- The DTI selected is tested in a bolt assembly with the same configuration and tensioning process as intended in the job, including whether the bolt head or nut is intended to be turned during the tensioning process.
- The bolt assembly, including the DTI, is assembled into a suitable tension calibrator according to manufacturer instructions
- The tensioning process intended to be used with the DTI's on the project is used to tension the bolt assembly until a tension of 1.05 times the minimum tension values specified in Table 8.5.5 of AS/NZS 5131 is reached.
- At this tension level, the average gap is measured to an accuracy of 0.025mm. This gap is termed the "calibrated gap"

The verified DTI's may be used for verification testing with the following constraints:

- The minimum required tension is indicated when the average of the verification DTI gaps is equal to or less than the 'calibrated gap'
- Verified DTI's cannot be used for the part turn method of tensioning because the deformation of the DTI consumes a portion of the turns provided
- When used for pre-installation verification of production DTI's, the verified DTI shall be located at the end of the bolt assembly opposite to the production DTI being verified
- When used for pre-installation verification of TCB's, the verification DTI shall be placed under the head of the TCB, with an additional washer placed between the bolt head and DTI. The bolt head is to be fixed against rotation and the nut rotated

- When used for pre-installation verification of torque-controlled methods of tensioning, the verification DTI shall be placed at the opposite end to the part (nut or bolt head) being rotated and an additional washer placed for the DTI protrusions to bear against. The part not rotated shall be fixed against rotation

C.6 Short bolts used with the part turn method of tensioning

Short bolts may not be suitable for the hydraulic tension calibrator and cannot use the verified DTI method for the part turn method of tensioning.

In this case it is acceptable to instal the short bolt assembly in a standard hole in a solid steel plate and apply the required turns. For the purposes of pre-installation verification, the bolt assembly is verified if it does not break or excessively deform under the required turns.

APPENDIX D

EXAMPLE INSPECTION AND TEST PLAN (ITP) FOR BOLTED CONNECTIONS

Logo	Project:						ITP No.:		
	Area:			Discipline: Structural	**ITP for bolted connection installation**		Revision		
		Inspection/test requirement			Reference document		Responsibility		Linked Record
Item	Activity	Characteristic to be checked	Method	Stage/ frequency	Code/ specification	Acceptance criteria	Bolting supervisor	Bolting inspector	
1	Inspection tasks prior to bolting								
1.1	Manufacturer certifications for bolt assemblies	Material properties, size	Review	Every batch	AS/NZS 1252.1	Complies			
1.2	Bolt assembly compliance	Packaging	Review	Every batch	AS 1111 AS/NZS 1252.1	Complies			
1.3	Bolt assembly identification	Marking	Inspect	One from every batch	AS 1111 AS/NZS 1252.1	Complies			
1.4	Bolt assembly traceability	Linkage between bolt batch number and connection location	Review	Every batch	Construction specification (Construction category)	If required			
1.5	Design requirements	Bolt assembly type (/S, /TB, /TF)	Review	Every connection	Construction specification	Complies			

		Threads included/excluded	Review	Every connection	Construction specification	Included or excluded			
1.6	Installation	Bolting procedure	Review	Every connection	Construction specification	Complies			
1.7	Connection configuration	Plate and hole alignment	Inspect	Every connection	AS/NZS 5131	Complies			
		Hole preparation	Inspect	Every connection	AS/NZS 5131	Complies			
		Contact surfaces	Inspect	Every connection	AS/NZS 5131	Complies			
1.8	Pre-installation verification	Verification testing	Witness		AS/NZS 5131				
1.9	Component storage	Protected storage	Inspect	Every batch	AS/NZS 5131	Complies			
2	Inspection tasks during snug tightening								
2.1	Fastener assembly installation	All fastener assemblies correctly installed	Inspect	Every connection	AS/NZS 5131	Complies			
		Correct placement of washers and DTI's (if used)	Inspect	Every connection	AS/NZS 5131	Complies			
2.2	Snug tightening	Correct procedure for snug tightening	Witness	Periodically	AS/NZS 5131	Complies			
		All bolts snug tightened	Inspect	Based on sampling plan	AS/NZS 5131	Complies			

2.3	Connection alignment after snug tightening	Gaps	Inspect	Every connection	AS/NZS 5131	Gaps less than maximum allowed			
2.4	Packing (if required)	Gaps after packing	Inspect	Every connection	AS/NZS 5131	Gaps less than maximum allowed			
		Packing arrangement	Inspect	Every connection	AS/NZS 5131	Complies			
3	Inspection tasks during tensioning								
3.1	Tensioning equipment	Operational and calibrated	Inspect	All equipment	AS/NZS 5131	Complies			
3.2	Match marking	Alignment	Inspect	Based on sampling plan	AS/NZS 5131	Complies			
3.2	Tensioning operation	Operation	Inspect	Based on sampling plan	AS/NZS 5131	Complies			
4	Inspection tasks after tensioning								
4.1	Match marking (or other indicator)	Angle (or other indicator)	Inspect	Every connection	AS/NZS 5131	Complies			
4.2	Document acceptance	Inspection sign-off	Document	After completion of each group of connections in a work area	AS/NZS 5131	Completed			

APPENDIX E

PROCESS FLOWCHART AND STAKEHOLDER RESPONSIBILITIES

E.1 Context

A range of stakeholders are involved in the eventual successful installation of a bolted connection. In particular, in relation to high strength tensioned bolted connections, the processes involved are inter-related and a number of stakeholders rely on a mutually shared understanding in order to ensure fit-for-purpose installed connections and satisfaction of duty of care under WHS Regulation.

It is therefore important that all stakeholders understand their role in the process, what they need to do and the information they need to share with others in, what in effect is, a chain of responsibility.

In order to clearly define these requirements, we need to identify the relevant stakeholders, clearly define a process and also assign responsibilities.

The responsibilities outlined below are outlined from a purely functional perspective, with no specific contractual model assumed. In reality, there are a number of different contractual models operating in current construction practice, each of which may introduce nuances to the assumed division of responsibilities detailed below. Regardless, the overarching responsible party (usually the builder and/or client) need to ensure the responsibilities noted below are assigned and actioned by a suitably qualified stakeholder.

It is pertinent to note that duty of care under WHS Regulation requires accepted practice to be actioned, unless there is good reason to do otherwise. The 'Safe design of structures code of practice' (Ref. 23) mandates specific duty of care for a range of stakeholders beyond just designers.

E.2 Stakeholders

A list of relevant stakeholders includes at least:

- Bolt assembly manufacturer
- Importer/supplier
- Bolt assembly procurer
- Steelwork erector / riggers
- Bolting crew
- Bolting supervisor / site supervisor
- Bolting inspector
- Builder
- Designer (structural engineer)
- Site/construction engineer
- Certifying authority representative (building certifier)

The responsibilities of each of these stakeholders is outlined below. The recommended process, which sets the context for these responsibilities, is outlined by the flowchart in Section E.14.

E.3 Responsibility of bolt assembly manufacturer

The bolt assembly manufacturer must:

1. Manufacture bolt assemblies to the requirements of AS/NZS 1252.1:2016 (Ref. 3). Bolt assemblies manufactured to previous versions of AS/NZS 1252 are not acceptable

2. Provide documentation as required by AS/NZS 1252.1:2016. A list of the required documentation is outlined in ASI Tech Note TN001 (Ref. 5)

E.4 Responsibility of importer / supplier

The importer/supplier must:

1. Ensure bolt assemblies are procured meeting the requirements of AS/NZS 1252.1:2016. <u>Bolt assemblies manufactured to previous versions of AS/NZS 1252 are not acceptable</u>
2. Undertake verification testing of each bolt batch to AS/NZS 1252.2 and provide the results to the purchaser. Refer Section 17.2
3. Ensure documentation as required by AS/NZS 1252.1:2016 is available. A list of the required documentation is outlined in ASI Tech Note TN001 (Ref. 5)
4. As recommended by AS/NZS 5131, provide a Supplier Declaration of Conformity (SDoC) to the purchaser for each batch of bolts. The contents and structure of a suitable SDoC is provided in ASI Tech Note TN001 (Ref. 5)
5. Provide support to the erector where difficulties are experienced with bolt installation on site

E.5 Responsibility of PROCURER / FABRICATOR

The bolt assembly procurer is usually the fabricator. The procurer must:

1. Request and obtain the documentation defined in AS/NZS 1252.1 to confirm the compliance of the bolt assemblies to AS/NZS 1252.1. ASI Tech Note TN001 (Ref. 5) outlines the required information
2. Request the documented outcomes of verification testing to AS/NZS 1252.2 for the batch or batches of bolts procured. Refer Section 17.2
3. Request a Supplier Declaration of Conformity from the supplier of the bolt assemblies for the batches procured. The contents and structure of a suitable SDoC is provided in ASI Tech Note TN001 (Ref. 5)
4. Maintain the bolt assemblies in the original packaging to ensure identification and traceability
5. Store bolt assemblies in ‘protected storage’ as defined in AS/NZS 5131

E.6 Responsibility of steelwork erector / riggers

The steelwork erector, who employs the riggers, must:

1. Ensure the riggers maintain bolt assemblies in original packaging in protected storage until they are immediately required for assembly into connections on site
2. Ensure connections are assembled to the requirements of AS/NZS 5131. Plies and bolt holes must be aligned and packers provided where necessary (refer Section 10). Bolts inserted in such a way as to not cause damage to the bolts
3. Confirm availability of and use of the approved Inspection and Test Plan (ITP) for erection of the structural steelwork in general and assembly of the bolted connections in particular. Refer Appendix D for an example ITP
4. Ensure traceability of bolt assemblies is maintained to the actual connections, if required by the construction specification. Refer Section 7.5

E.7 Responsibility of bolting crew

The members of the bolting crew must:

1. Ensure appropriate personal protective equipment (PPE) is used at all times
2. Be familiar with and trained in the type of structural connections to be installed
3. Confirm the installation equipment (spanners, powered tools) is working correctly

4. Correctly undertake the snug tightening and tensioning (where required) of the bolted connections. Refer Sections 11 and 12 for snug tightening and tensioning respectively
5. Inform the bolting supervisor where issues arise

E.8 Responsibility of bolting supervisor / site supervisor

The bolting supervisor must:

1. Be familiar with and trained (refer Note 1) in the type of structural connections to be installed
2. Ensure trained competent bolting crew are utilised.
3. Prepare a Work Method Statement (WMS) for the bolting procedure. Provide bolting crews with clear instructions on the bolting procedures to be undertaken
4. Review compliance documentation for the bolt assemblies to be installed
5. Review bolting assembly identification and traceability to ensure it is complete and matches the compliance documentation
6. Review connection types and ensure correct bolts and correct installation method used for each of /S, /TB and /TF connections
7. Implement ITP's and work method statements
8. Inspect a statistically appropriate number of connections at the completion of snug tightening to ensure the snug tightening process is correctly implemented by the bolting crews. Refer Section 15
9. Inspect and sign off connections after completion of tensioning. Refer Section 15
10. Complete documentation as required by the ITP's

**Note 1: As of the date of publication of this Tech Note, ASI has been successful in securing a Standards Australia project to develop a new Part to AS 2214 (Ref. 25) specifically defining qualification requirements for bolting supervisors and inspectors. In due course industry can expect recognised training courses to be developed for bolting supervisors and inspectors.*

E.9 Responsibility of bolting inspector

The bolting inspector would normally be a third party employed by the client or builder to ensure compliance of the completed bolted connections. The bolting inspector must:

1. Ensure appropriate personal protective equipment (PPE) is used at all times
2. Have familiarity with and review the ITP's for the bolting
3. Inspect all or a statistically appropriate number of the connections. Inspection should be undertaken after snug tightening and then after completion of tensioning. Refer Section 15
4. Provide an inspection report to the builder and certifying engineer

E.10 Responsibility of builder

The builder must:

1. Ensure procurement of compliant bolt assemblies. Where necessary, organise testing if compliance cannot be clearly and rigorously established. Knowing the current procurement environment and the issues described in ASI Tech Note TN001, it is simply not appropriate to procure bolt assemblies and then, after the fact, pressure the responsible engineer to certify. <u>The responsible engineer MUST be involved in the procurement decisions</u>.
2. Ensure all documentation for procured assemblies, as prescribed by the Standards, is available for inspection. ASI Tech Note TN001 (Ref. 5) outlines the required documentation
3. Manage bolt installation under a recognised quality management system
4. Ensure appropriate work method statements and ITP's have been prepared and are followed. Appendix D provides an example of an appropriate ITP
5. Organise inspection and sign-off of completed connections. Refer Section 15

E.11 Responsibility of designer (structural engineer)

The designer must:

1. Design bolted connections to the requirements of AS 4100 (Ref. 1)
2. Ensure the design documentation is complete and correctly specifies the requirements for the bolted connections
3. Work with the building certifier to ensure compliant outcomes. Refer Ref. 26

Where contracted to do so:

1. Review procurement documentation to establish compliance of bolt assemblies. Mandate testing where compliance cannot be rigorously established
2. Review ITP’s and work method statements
3. Inspect bolt installation prior, during and after installation. Refer Section 15
4. Provide certification for the final structure assembly if, and only if, the compliance of the procured bolt assemblies and the installation methodology has been properly verified by the engineer responsible for the certification. The engineer responsible for the certification must have inspected the bolt assembly installation and completed connections if not in receipt of a report from a third-party bolting inspector

E.12 Responsibility of site/construction engineer

The site or construction engineer may be different to the engineer responsible for design of the structure.

The site/construction engineer must:

1. Review the construction specification and ensure clarity on connection types and proposed installation procedures. Liaise with design engineer where required
2. Review the ITP’s and ensure appropriate for and consistent with the requirements of the construction specification. Appendix D provides an example of an appropriate ITP
3. Meet with the erector and bolting supervisor to ensure alignment in understanding of the bolting processes, implementation of the ITP’s and staging for any inspections that may be required by the site/construction engineer, design engineer and/or certifying authority
4. Inspect a statistically appropriate number of the bolted connections after snug tightening and then after tensioning. Refer Section 15
5. Review and approve the completed documentation provided by the bolting supervisor
6. Work with the building certifier to ensure compliant outcomes. Refer Ref. 26

E.13 Responsibility of certifying authority

The certifying authority confirms the regulatory requirements for the project are completed correctly. In respect of structural aspects, the authority will usually require a documented certification from the engineer of record, usually the design engineer.

The certifying authority must:

1. During the course of the project, engage with the design engineer, site engineer and builder as required to fulfil the mandated regulatory process
2. Specifically review the basis for compliance of the construction products utilised, in this case the structural bolt assemblies
3. Review the documentation and process undertaken by the certifying engineer
4. Only accept a certification where it can be confirmed that the certifying engineer has undertaken appropriate inspections

Engineers Australia has recently published a guide for design engineers and building certifiers (Ref. 26) that provides clarity on the roles and interaction required.

E.14 Bolting installation process

The bolting installation process is defined in the process flowchart in Figure E.1. The flowchart is segmented into the main stakeholder groups, being:

- Bolt supplier
- Fabricator
- Engineer (design and/or site)
- Builder/erector
- Bolting inspector

The flowchart references back to the sections in this Appendix defining responsibilities.

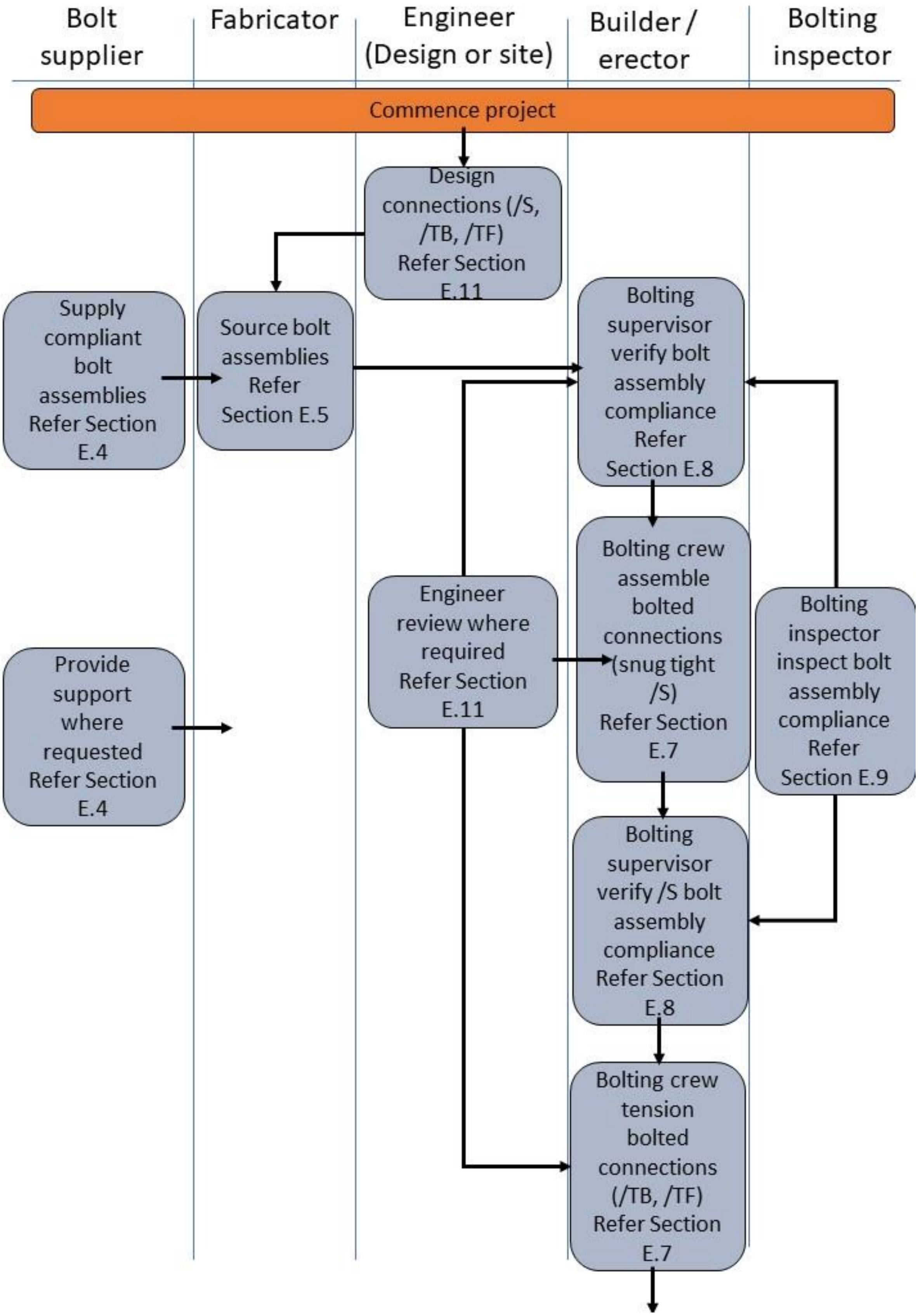


Figure E.1 Process Flowchart (Part 1 of 2)

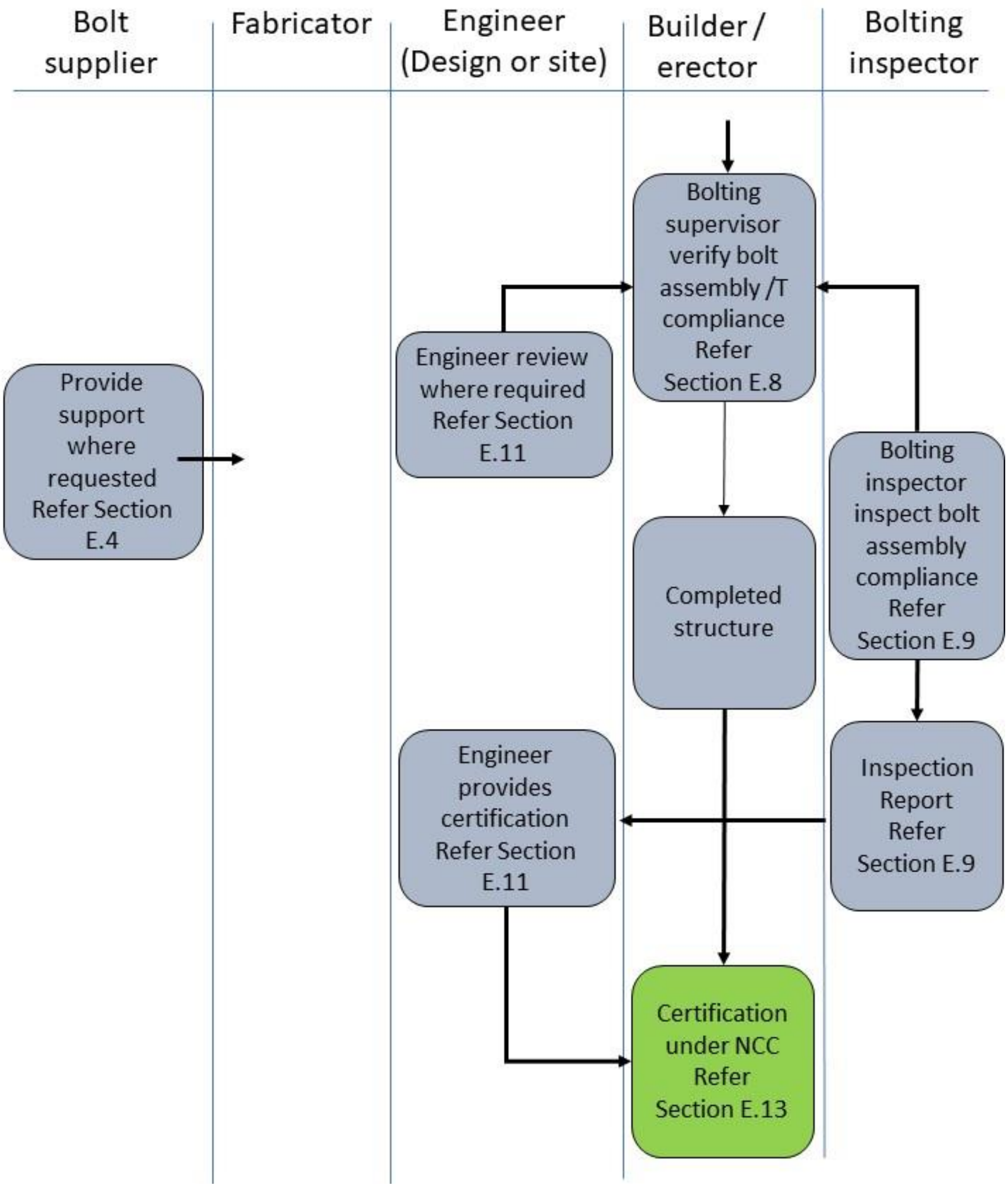


Figure E.1 Process Flowchart (Part 2 of 2)