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Steel structures — Execution of structural steelwork —

Part 6: **Bolting**

Structures en acier – Exécution des charpentes et ossatures en acier —

Partie 6: Boulonnage

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 167, *Steel and aluminium structures*.

This first edition cancels and replaces ISO 10721-2:1999, which has been technically revised.

A list of all parts in the ISO 17607 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Specific requirements for the achievement of structures that are optimal with respect to safety, the state of the economy, development and general values of a nation are given in the appropriate regional or national standards, if they exist.

Many nations do not have their own standards for structural steelwork. Some reference other national or regional standards. Some permit the project's standard to be selected by the owner, designer or constructor of the structure. Some do not require any standards to be followed.

The ISO 17607 series of standards on the execution of structural steelwork was developed to serve as a means to provide a set of requirements and guidance for projects that are constructed without a governing regional or national standard. The ISO 17607 series can also serve to reduce trade barriers.

Additional requirements to be addressed in the execution of structural steelwork, as structures or as fabricated components, can be found in the other parts of the series:

— ISO 17607-1 (General requirements and terms and definitions);

— ISO 17607-2 (Steels);

— ISO 17607-3 (Fabrication);

— ISO 17607-4 (Erection);

— ISO 17607-5 (Welding).

Steel structures — Execution of structural steelwork —

Part 6: Bolting

1 Scope

This document defines the general requirements for structural bolting in the execution of structural steelwork as structures or as fabricated components, in conjunction with ISO 17607-1.

Additional requirements to be addressed in the execution of structural steelwork, as structures or as fabricated components, can be found in other parts of ISO 17607.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread*

ISO 898-2, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes – Coarse thread and fine pitch thread*

ISO 898-3, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 3: Flat washers with specified property classes*

ISO 2859-5, *Sampling procedures for inspection by attributes — Part 5: System of sequential sampling plans indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 3506-1, *Mechanical properties of corrosion-resistant stainless-steel fasteners — Part 1: Bolts, screws and studs*

ISO 3506-2, *Mechanical properties of corrosion-resistant stainless-steel fasteners — Part 2: Nuts*

ISO 4014, *Hexagon head bolts - Product grades A and B*

ISO 4017, *Fasteners – Hexagon head screws – Product grades A and B*

ISO 4032, *Hexagon nuts (style 1) - Product grades A and B*

ISO 4033, *Hexagon nuts, (style 2) - Product grades A and B*

ISO 4042, *Fasteners — Electroplated coating systems*

ISO 6789-1, *Assembly tools for screws and nuts — Hand torque tools — Requirements and test methods for design conformance testing, quality conformance testing and recalibration procedure*

ISO 7089, *Plain washers — Normal series — Product grade A*

ISO 7090, *Plain washers, chamfered — Normal series — Product grade A*

ISO 7091, *Plain washers — Normal series — Product grade C*

ISO 7092, *Plain washers — Small series — Product grade A*

ISO 7093-1, *Plain washers — Large series — Part 1: Product grade A*

ISO 7093-2, *Plain washers — Large series — Part 2: Product grade C*

ISO 7094, *Plain washers — Extra large series — Product grade C*

ISO 10683, *Fasteners — Non-electrolytically applied zinc flake coating systems*

ISO 10684, *Fasteners — Hot dip galvanized coatings*

ISO 14713-3, *Zinc coatings — Guidelines and recommendations for the protection against corrosion of iron and steel in structures — Part 3: Sherardizing*

ISO 16228, *Fasteners — Types of inspection documents*

ISO 17607-1, *Steel structures — Execution of structural steelwork — Part 1: General requirements and vocabulary*

ISO 17607-2, *Steel structures — Execution of structural steelwork — Part 2: Steels*

ISO 17607-3, *Steel structures — Execution of structural steelwork — Part 3: Fabrication*

ISO 17607-4, *Steel structures — Execution of structural steelwork — Part 4: Erection*

ISO 17607-5, *Steel structures — Execution of structural steelwork — Part 5: Welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17607-1 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Execution specification and quality requirements

4.1 General

See ISO 17607-1 for execution levels, identification, traceability, and quality requirements.

4.2 Execution specification

National standards and documents that provide technically equivalent conditions may be used, in whole or in part, in place of referenced ISO standards or requirements of this document. In these cases, the technically equivalent national standards and documents, and deviations from the requirements of this document, shall be referenced in the execution specification.

The necessary information and technical requirements for execution of structural bolting shall be agreed on and complete before commencement.

The execution specification shall include the following items (see Annex A) as relevant:

a) required additional information, see A.1;

b) options that may be specified, see A.2;

c) quality requirements related to execution levels, see A.3.

There shall be procedures for making alterations to a previously agreed execution specification.

5 Constituent products

5.1 General

5.1.1 Selection of constituent products

See ISO 17607-1 for selection of constituent products.

5.1.2 Verification of conformance

See ISO 17607-1 for verification of conformance with the order and either relevant standards or specified requirements, or both.

Inspection documents shall be supplied in accordance with ISO 16228, as listed in Table 2, with the information in Table 1 as required.

Table 1 — Inspection reporting for structural bolting products, by requirement

Type of requirement Method of control	Required limit(s) expressed as:	Reported
Chemical composition	Min and max, as applicable	Measured value
Mechanical properties (yield strength, tensile strength, hardness)	Min	Minimum value measured
	Max if applicable	Maximum value measured
	Min and max	Minimum and maximum value measured
Mechanical property (proof load)	Pass/Fail	Conform
Surface condition (carburization/decarburization)	Pass/Fail	Conform
Measurement (Geometry, tolerances)	Min	Minimum value measured
	Max	Maximum value measured
	Min & max	Minimum and maximum value measured
Dimensional attribute (gauge)	Go	Conform
	No-Go	
	Go/No-Go	
Bolting assemblies for preloading (k-value or COV, or both, if required)	k-class, if applicable	k-class
Inspection (VT, MT)	Pass/Fail	Conform

Table 2 — Inspection documents for structural bolting products according to ISO 16228

Constituent product	Inspection documents [a]
Structural bolting assemblies suitable for pretensioning	F3.1[b]
Structural bolting assemblies	F2.1
Bolts[c], nuts[c], or washers[c]	F2.1

[a] If assemblies are marked with a manufacturing lot number and the manufacturer can trace the measured characteristic values from the internal (factory) production control records on the basis of this number, the F3.1 inspection certificate or F2.1 declaration of conformity may be omitted.

[b] The inspection documents shall include the results of the suitability tests, if required.

[c] Applicable if bolts, nuts or washers are supplied for use in non-pretensioned applications, or not as a component of a bolting assembly.

5.2 Structural bolting products

5.2.1 Property classes

Property classes of bolts and nuts and, if appropriate, coatings, shall be specified together with any required options within the product standard.

Structural bolting components and assemblies shall be selected from Annex B.

The mechanical properties shall be specified for:

a) carbon and alloy steel bolting assemblies with larger diameters than those specified in ISO 898-1, ISO 898-2 and ISO 898-3;

b) austenitic or austenitic-ferritic stainless-steel bolting assemblies with larger diameters than those specified in ISO 3506-1 and ISO 3506-2, or those specified in other relevant national standards;

c) atmospheric corrosion-resistant bolting assemblies.

5.2.2 Structural bolting assemblies for non-pretensioned applications

Bolts, nuts, washers, and bolting assemblies that conform to the appropriate product standards as given in Table B.1 through Table B.5 may be used for non-pretensioned applications.

5.2.3 Structural bolting assemblies for pretensioned applications

High-strength structural bolts, nuts, washers and bolting assemblies that conform to the appropriate product standards as given in Table B.1 through Table B.3 may be used for pretensioned applications.

Unless specified in the execution specification, stainless-steel bolts shall not be used in pretensioned applications. If used in pretensioned applications, they shall be treated as special fasteners.

5.2.4 Washers

5.2.4.1 General

Washers that conform to the appropriate product standards as given in Table B.3, or are included as a part of bolting assemblies as given in Table B.1 or Table B.2, may be used for pretensioned applications.

Washers that conform to the appropriate product standards as given in Table B.3 or Table B.5, or are included as a part of bolting assemblies as given in Table B.1, Table B.2, or Table B.4, may be used for non-pretensioned applications.

5.2.4.2 Taper washers

Taper washers shall conform with the relevant product standard for flat washers, except for dimensions applicable to shape, which shall be specified.

NOTE Taper washers are also known as bevelled washers.

5.2.4.3 Plate washers

Plate washers shall be dimensioned with nominal clearances according to Annex C and have dimensions that ensure that the washer overlaps the connected component by at least as much as a standard plain washer would when used with standard round holes.

5.2.5 Direct tension indicators

Direct tension indicators and associated hardened nut face and bolt face washers that conform to the appropriate product standards as given in Table B.6 may be used.

When direct tension indicators are used with bolts loaded in axial tension, the potential loss of pretension should be considered[91].

Direct tension indicators shall not be used with stainless-steel bolts.

If direct tension indicators are used with atmospheric corrosion-resistant bolts, the direct tension indicators shall also be atmospheric corrosion resistant.

NOTE Type 3 direct tension indicators in accordance with ASTM F959/F959M can be suitable as atmospheric corrosion resistant.

5.2.6 Alternative direct tension indicators

Alternative direct tension indicators other than those listed in Table B.6 may be used if permitted by the execution specification.

a) Detailed installation instructions shall be available in a supplemental specification that shall provide, as a minimum, for the:

   1) required character and frequency of pre-installation verification;

   2) alignment of bolt holes to permit insertion of the bolt without undue damage to the threads;

   3) placement of bolting assemblies in all types and sizes of holes, including placement and orientation of the direct tension indicator and other washers;

   4) systematic assembly of the joint, progressing from the most rigid part of the joint until the connected plies are in firm contact;

   5) subsequent systematic pretensioning of all bolts in the joint, progressing from the most rigid part of the joint in a manner that will minimize relaxation of previously pretensioned bolts.

b) Detailed inspection instructions shall be available in a supplemental specification that shall provide, as a minimum, for:

   1) observation of the required pre-installation verification testing;

   2) subsequent routine observation to ensure the proper use of alternative direct tension indicators.

5.2.7 Coated structural bolting components

The corrosion resistance of coated structural bolting components shall be comparable to that specified for the connected components.

Hot-dip galvanized coatings, non-electrolytically applied zinc flake coatings, electroplated coatings, or other coatings of structural bolting components appropriate with the product standards given in Table B.9 may be used, or, in the absence thereof, with the bolting component manufacturer's recommendation.

Protective coatings of structural bolting components shall conform with the requirements of the relevant product standard or, in the absence thereof, with the manufacturer's recommendation.

For bolts of property class 10.9 or equivalent tensile strength or higher, electroplated coatings shall not be used.

NOTE Attention is drawn to the risk of hydrogen embrittlement of electroplated or hot dip galvanized bolts of property class 10.9 or equivalent tensile strength or higher.

5.2.8 Atmospheric corrosion-resistant structural bolting components

The chemical composition of the material of atmospheric corrosion-resistant structural bolting components shall be specified.

5.2.9 Locking devices

If required, devices shall be specified that effectively prevent loosening or loss of pretension of the assembly if subjected to impact, significant vibration, or cyclic loading.

NOTE 1 The use of wedge-locking washers, and the use of double-nutting with proper tightening techniques, have been shown to minimize loss of bolt pretension from self-loosening. Locking devices cannot prevent loss of pretension from relaxation or creep.

To prevent nuts from becoming disengaged from bolts, prevailing torque nuts from ISO 7040, ISO 7042, ISO 7719, and ISO 10511, and the performance requirements given in ISO 2320, can be used unless otherwise specified.

NOTE 2 ISO 2320 includes a test to determine either the performance properties or the torque/clamp force properties, or both, for prevailing torque type steel nuts.

5.2.10 Special structural fasteners

When permitted by the execution specification, special structural fasteners may be used:

— if the property class does not exceed grade 10.9 (or equivalent tensile strength);

— if the bolting component type is subjected to initial testing representative of the product type to demonstrate that its performance is suitable.

Initial testing parameters should include relevant testing requirements for comparable products listed in Annex B.

Detailed installation instructions shall be available in a supplemental specification in accordance with 7.9.

NOTE 1 The use of special fasteners is addressed in 7.9.

NOTE 2 Resin injection bolts are classified as special fasteners and are addressed in EN 1090-2.

5.2.11 Packaging

Structural bolting components shall be suitably packed for transportation and shall be identified in accordance with the relevant product standard. The contents of all packages shall be clearly displayed.

NOTE Consideration for packaging suitability can include needs for handling, durability, water resistance, puncture resistance, and related concerns.

5.2.12 Test reports

If required, the manufacturer or supplier test reports documenting conformance to the applicable specifications for all components used in structural bolting shall be available on delivery and before assembly or erection of structural steel.

5.2.13 Delivery and identification

Structural bolting components and bolting assemblies shall be delivered in unopened and complete packages.

Structural bolting components and bolting assemblies according to 5.2.2 to 5.2.5 shall be marked, delivered and identified in accordance with the requirements of the relevant product standard.

Atmospheric corrosion resistant bolting assemblies, foundation bolts, locking devices, plate washers, and special fasteners shall be marked in accordance with the product standard, if applicable, delivered in suitable packaging, and identified as follows:

a) labelled such that the content is readily identifiable;

b) labelled or documented in accordance with the relevant product standard with the following information in a legible and durable form:

   — manufacturer's identification and, if relevant, lot numbers;

   — type of structural bolting component and material and, if appropriate, its assembly;

   — protective coating, if applicable.

5.2.14 Storage of structural bolting components and assemblies

Structural bolting components and assemblies shall be divided by grade, size, length and lot number. They shall be protected from dirt and moisture in closed containers in a protected shelter at the site of installation.

The manufacturer's instructions shall be followed when stacking packages.

Only as many bolting components that are anticipated to be installed during the work shift shall be taken from protected storage. Components that are not incorporated into the work shall be returned to protected storage at the end of the work shift. Components shall not be cleaned or modified from the as-delivered condition.

High-strength bolts shall be handled carefully to prevent thread damage. In addition to thread damage, spline-drive assemblies shall be handled carefully to prevent spline damage.

5.2.15 Reconditioning of structural bolting components and assemblies

Bolting components to be installed using torque control methods, including spline-drive assemblies, that accumulate rust, dirt, or moisture, shall not be incorporated into the work unless they are requalified through testing.

Spline-drive assemblies and those bolting components to be installed using torque control methods that fail requalification testing, shall be returned to the manufacturer or supplier for reconditioning,

including cleaning, relubrication, and retesting, unless these operations are permitted by the execution specification to be performed by others. Such reconditioning shall follow written procedures with requirements for lubrication products, batch control, process control, sampling, and a suitable test method to verify that the reconditioned assemblies provide the required pretension within the permitted range, if any.

5.3 Studs and shear connectors

Threaded studs for arc stud welding shall be in accordance with ISO 17607-5.

Requirements for other types of shear connectors for bolted connections shall be classified as special fasteners.

5.4 Anchorages

5.4.1 Foundation bolts

The mechanical properties of rods used as foundation bolts shall be in accordance with ISO 898-1, ISO 3506-1 or fabricated from hot-rolled carbon, low-alloy, or stainless steel. The execution specification shall specify the required properties.

Unless otherwise specified in the execution specification, steel reinforcing bars shall not be used. When permitted in the execution specification, steel reinforcing bars shall be of a weldable grade, and the grade shall be specified in the execution specification.

5.4.2 Other anchorage systems

The execution specification shall specify if proprietary products shall be used.

6 Preparation and assembly

6.1 General

This clause applies to holes for connections with bolts, pins, and foundation bolts.

6.2 Holes for structural bolting

6.2.1 General

The nominal clearance shall be selected from Annex C. Unless specified in the execution specification, the nominal clearance for bolt holes shall be as specified in Table C.1.

The nominal clearances for bolts and for pins not intended to act in fitted conditions shall be specified in the execution specification. The nominal clearance is:

— for round holes, the difference between the nominal hole diameter and the nominal bolt diameter;

— for slotted holes, the difference between the length or the width of the hole and the nominal bolt diameter.

NOTE 1 Annex C provides information on nominal clearances as stated in several national standards.

NOTE 2 The nominal hole diameter combined with the nominal diameter of the bolt to be used in the hole, determines whether the hole is standard or oversized. The terms "short" and "long" applied to slotted holes refer to two types of holes used for the structural design of pretensioned bolts, and with limitation, non-pretensioned bolts. These terms are also used to designate clearances for non-pretensioned bolts.

The execution specification shall specify special dimensions for movement joints.

6.2.2 Dimensions of holes

6.2.2.1 General

Unless otherwise specified in the execution specification, the dimensions of holes shall provide the nominal clearance defined in 6.2.1.

6.2.2.2 Slotted holes

When permitted by the execution specification:

— short-slotted holes can be used in any or all plies of non-pretensioned joints and pretensioned bearing joints, provided the applied load is approximately perpendicular (between 80° and 100°) to the axis along the length of the slot;

— short-slotted holes can be used in any or all plies of slip-resistant joints without regard for the direction of the applied load;

— long-slotted holes can be used in only one ply at any individual faying surface of non-pretensioned joints and pretensioned bearing joints, provided the applied load is approximately perpendicular (between 80° and 100°) to the axis along the length of the slot;

— long-slotted holes can be used in one ply only at any individual faying surface of slip-resistant joints without regard for the direction of the applied load.

NOTE Fully inserted shims between the faying surfaces of load-transmitting elements of bolted joints are not considered a long-slotted element of a joint, nor are they considered to be a ply at any individual faying surface. See 6.3 and 6.4.2 for requirements for faying surfaces of shims and packing.

6.2.2.3 Holes for fit bolts

For fit bolts, the nominal hole diameter shall be equal to the shank diameter of the bolt.

NOTE For fit bolts conforming to EN 14399-8, the nominal diameter of the shank is 1 mm larger than nominal diameter of the threaded portion.

6.2.2.4 Holes for countersunk bolts

For countersunk bolts, nominal dimensions of the countersinking and tolerances on those shall be such that, after installation, the bolt shall be flush with the outer face of the outer ply. The dimensions of the countersinking shall be specified accordingly.

If countersunk bolts are identified as being for use in tension or in pretensioned applications, the nominal depth of countersinking shall be at least 2 mm less than the nominal thickness of the outer ply.

NOTE The 2 mm is to allow for adverse tolerances.

6.2.2.5 Holes in base plates for foundation bolts

If the nominal clearance of the base plate hole is 3 mm or larger, but not more than 8 mm, a round or square plate washer of thickness not less than 4 mm shall be used under the nut.

In addition, for foundation bolts above 20 mm in diameter d with a minimum specified yield strength of 400 MPa or less:

— the maximum base plate hole diameter is $1{,}5 \times d$;

— the minimum outside diameter of the plate washer plate is $1{,}75 \times d + 20$ mm;

— the minimum plate washer thickness is $0{,}4 \times d$.

For foundation bolts with a minimum specified yield strength greater than 400 MPa, thicker plate washers can be required.

NOTE The above dimensions can be considered suitable for columns supporting gravity loads only, and for columns with low levels of moment at the column base.

6.3 Faying surfaces for bearing-type joints

The faying surfaces of bearing connections, whether with non-pretensioned or pretensioned bolts, shall be free of dirt and other foreign material, and are permitted to be uncoated, coated with protective coatings of any formulation, or galvanized, as specified in the execution specification. In addition, surfaces adjacent to the bolt head and nut, or washer(s), if used, shall be free of dirt and other foreign material.

Surface preparation and protective coating requirements also apply to packing plates and shims.

6.4 Preparation of friction surfaces in slip-resistant joints

6.4.1 General

This clause does not address corrosion protection of the structural steel.

6.4.2 Surface preparation

The slip factor for slip-resistant joints shall be specified in the execution specification.

Surface preparation and protective coatings that provide a designated minimum slip factor in accordance with specific national standards shall be selected from Table D.1.

Uncoated faying surfaces, including parts of surfaces in contact with washers, shall be free of scale, except tight mill scale, and free of loose rust, dust, oil, welding spatter, paint, lacquer or other coatings, including overspray, other than those specified in the execution specification, in areas closer than one bolt diameter but not less than 25 mm from the edge of any hole and in all areas within the bolt pattern. If this condition cannot be achieved, the faying surface shall be blast cleaned. See Figure 1.

Coated faying surfaces shall first be blast cleaned and subsequently coated with a coating that meets or exceeds the required slip resistance that is either qualified in accordance with the requirements in Annex P or listed in Table D.1.

Packing plates and shims shall have a surface preparation that provides the same or better slip coefficient as the connected material. See 7.2.3.

6.4.3 Precautions prior to assembly

The following precautions shall be taken prior to assembly:

a) drilling of holes shall be completed prior to blasting;

b) the friction surfaces shall be free from all contaminants, such as oil, dirt, or coatings other than those specified for the friction surface;

c) uncoated surfaces shall be free from loose rust and other loose material;

d) care shall be taken not to damage or smooth the roughened surface;

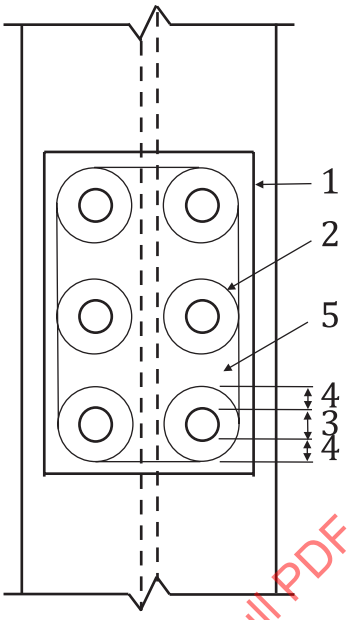
e) when splice plates are temporarily fixed to a member, temporary bolts may be used;

f) the plies of joints with coated faying surfaces shall not be assembled before the coating has cured.

When a grinder is used on the periphery of bolt holes for the removal of burrs after blasting, either:

g) the ground area adjacent to the hole(s) shall be re-blasted, or

h) the as-ground surface shall be exposed until red rust generation has occurred.



Key

1	perimeter of contact area of faying surfaces	4	bolt diameter or 25 mm, whichever is greater
2	circular area around bolt (typical)	5	area within the bolt pattern
3	bolt diameter		

Figure 1 — Coated faying surface for slip-resistant joints

6.5 Assembly

Loose material that would prevent solid seating of the connecting parts shall be removed before assembly.

For pretensioned and slip-resistant joints, excessive coating thickness that can cause substantial loss of bolt pretension shall be evaluated, unless otherwise approved in the execution specification.

Loss of pretension can be evaluated by testing as described in Annex Q.

When assembled, connections shall be in close contact and shall not be separated by free spaces or compressible materials.

Assembly of components shall be carried out within the tolerances specified in ISO 17607-3 or ISO 17607-4, as applicable.

Precautions shall be taken to prevent galvanic corrosion produced by contact between different metallic materials.

Holes (e.g. for fit bolts) for which enlargement by reaming or cutting is not permitted shall be identified and not be used for alignment.

NOTE Additional holes specifically meant for alignment can be provided where connection holes cannot be used for alignment.

7 Structural bolting

7.1 General

This clause covers requirements for shop and site bolting of steel-to-steel connections using structural bolting components and assemblies.

7.2 Joint types and assembly

7.2.1 Joint type

The execution specification shall identify the joint type as a non-pretensioned joint, pretensioned joint, or slip-resistant joint.

7.2.2 Fit of joint and shims

The connected components shall be drawn together to achieve firm contact when assembled and shall not be separated by significant free spaces or compressible materials.

Shims may be used to adjust the fit in connections and the alignment of the structure. If the gap between the connected parts at the structural bolts is 1 mm or less, no shimming is required. If the gap between the connected parts at the structural bolts exceeds 1 mm, shims shall be used to reduce the gap to 1 mm or less.

For constituent products with $t > 4$ mm for plates and $t > 8$ mm for sections, unless full contact bearing is specified, residual gaps of up to 4 mm may be left at the edges when contact bearing is achieved at the central part of a connection.

Shims shall be made of flat steel unless otherwise permitted in the execution specification.

Shims shall have similar durability to that of the structure. If shims are used to align structures composed of coated material, the shims shall be protected in a similar manner to provide the specified durability, unless the shims are required to meet a specified friction slip factor.

Shims shall be secured where they are at risk of coming loose. For execution levels EXL3 and EXL4, if welding is used to secure shims, the welding shall be in accordance with ISO 17607-5.

For slip-resistant joints, distortion, warping, or bending of the joint, splice plates or the connected members caused by welding, weld spatter, and burrs resulting from drilling, etc., shall be corrected and repaired with care not to damage the friction surfaces.

If lack-of-fit between erected components cannot be corrected by the use of shims, components of the structure shall be locally modified in accordance with the methods specified in ISO 17607-4. The modifications shall not compromise the performance of the structure in the temporary or permanent state. This work may be executed on site. Care shall be taken with structures built of welded latticed components and space-frame structures to ensure that they are not subjected to excessive forces in an attempt to force a fit against their inherent rigidity.

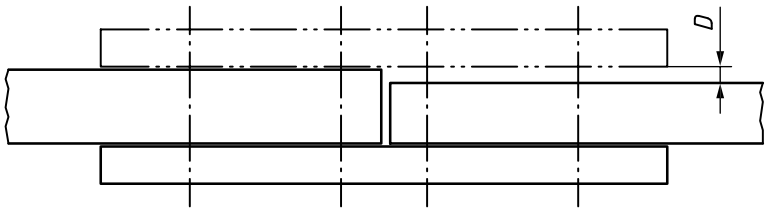
Permanent connections shall not be made between components until the structure has been aligned, levelled, plumbed and temporarily connected to ensure that components will not be displaced during subsequent erection or alignment of the remainder of the structure.

7.2.3 Packing plates

Packing plates shall be provided wherever necessary to ensure that the load-transmitting plies are in firm contact when the connection is tightened to the snug-tight condition. All packing plates shall be steel with a surface condition similar to that of the adjacent plies.

NOTE Packing plates are also referred to as filler plates when thick, or as shim plates when thin.

Separate components forming part of a common ply shall not differ in thickness by more than *D*, where *D* is 1 mm, see Figure 2. If steel packing plates are provided to ensure that the difference in thickness does not exceed the above limit, their thickness shall not be less than 1 mm.



Key

D difference in thickness

Figure 2 — Difference in thickness between components of a common ply

In case of severe exposure, avoiding cavity corrosion can require closer contact.

Plate thickness shall be chosen to limit the number of packing plates to a maximum of three.

Packing plates shall have compatible corrosion behaviour and mechanical strength with the adjacent plate components of the connection. Full consideration shall be given to the risk and implication of galvanic corrosion resulting from dissimilar metals being in contact.

7.2.4 Snugging of joint

Each structural bolt assembly shall be brought at least to a snug-tight condition. Special care shall be given to avoid over-tightening, especially for short bolts and bolts of diameter M12 or smaller.

7.2.5 Sequence of tightening

The tightening process shall be carried out from structural bolt to structural bolt of the bolt group, starting from the most rigid part of the connection and moving progressively towards the least rigid part in a manner that will minimize relaxation of previously pretensioned bolts. To achieve a uniform snug-tight condition, more than one cycle of tightening can be necessary.

NOTE 1 The most rigid part of a cover plate connection of an H section is commonly in the middle of the connection bolt group. The most rigid parts of end plate connections of H sections are usually beside the beam or girder flanges.

For combined joints comprising both high-strength structural bolts and welding, in general, high-strength structural bolts shall be fastened first, followed by welding.

NOTE 2 In general, for combined connections such as beams where the webs are connected by high-strength structural bolts and the flanges connected by welding, the high-strength structural bolts are tightened first, followed by welding.

In combined connections, when the depth of a beam or the thickness of a beam flange is large, when bolt tightening is done first followed by welding, it should be considered that partial bolt tightening is done first, followed by welding, and then final bolt tightening.

NOTE 3 In combined connections as described above, there is a possibility that defects such as cracks of welds can occur.

7.2.6 Structural bolts

7.2.6.1 Bolt diameter

The nominal bolt diameter used for structural bolting shall be at least M12 unless specified in the execution specification together with the associated requirements.

7.2.6.2 Threads outside shear plane

If it is intended that a connection utilises the shear capacity of the unthreaded shank of structural bolts, then the dimensions of the structural bolts shall be specified to allow for the tolerances on the length of the bolt and the unthreaded portion. For connected parts of unequal thicknesses, if required, the orientation of the bolt shall also be specified.

7.2.6.3 Threads in grip

For non-pretensioned structural bolts, at least one full thread (in addition to the thread run-out) shall remain clear between the bearing surface of the nut and the unthreaded part of the shank, unless otherwise stated in the execution specification.

For pretensioned structural bolts, at least two threads shall be between the bearing surface of the nut and the unthreaded part of the shank, unless otherwise stated in the execution specification.

When regional or national standards are used, threads in the grip shall meet the requirements of Annex F.

7.2.6.4 Thread protrusion

After tightening, at least one thread protrusion shall extend beyond the outer face of the nut when installed, unless otherwise stated in the execution specification.

When regional or national standards are used, thread protrusion shall meet the requirements of Annex F.

7.2.7 Nuts

Nuts shall run freely on their partnering structural bolt, which is checked during hand assembly. Any uncoated bolting assembly where the nut does not run freely shall not be used. Coated assemblies shall not be used for pretensioned applications where the nut does not run with low resistance to rotation when using hand tools.

NOTE Hot dip galvanized bolts can have areas in the bolt or nut threads where excess zinc creates resistance to rotation of the nut.

If a power tool is used, either of the following two checks may be used:

a) for each new batch of nuts or structural bolts, their compatibility may be checked by hand assembly before installation;

b) for mounted bolt assemblies but prior to tightening, sample nuts may be checked for free-running by hand after initial loosening.

Nuts shall be installed so that their required identification markings are visible for inspection after installation.

7.2.8 Washers

7.2.8.1 General

If washers are required, it shall be specified whether washers are to be placed under the nut or under the bolt head, whichever is to be rotated, or both.

For lap (shingle) joints between thin plate or sheet with only one row of bolts perpendicular to the direction of stress, washers should be used under both bolt head and nut to reduce bending of the connected parts.

NOTE 1 In general, for non-pretensioned structural bolts, washers are not necessary with standard round holes.

NOTE 2 The use of washers can reduce local damage to protective coatings on steel, particularly where these are thick coatings.

7.2.8.2 Washer requirements for pretensioned bolts

For pretensioned structural bolts, unless otherwise specified, hardened washers (or if necessary, hardened taper washers) shall be used as follows:

a) for grade 8.8 or equivalent tensile strength structural bolts, a washer shall be used under the bolt head or the nut, whichever is to be rotated;

b) for grade 10.9 or equivalent tensile strength structural bolts installed in steel with yield strength of 300 MPa or lower, washers shall be used under both the bolt head and the nut;

c) for grade 10.9 or equivalent tensile strength structural bolts installed in connected material of specified minimum yield strength above 300 MPa, a hardened flat washer shall be used under the bolt head or nut, whichever is to be rotated.

When an oversized or slotted hole occurs in an outer ply, the washer requirements shall be as prescribed in Table 3. The washer used shall be of sufficient size to completely cover the hole.

Table 3 — Washer and plate washer requirements for oversized and slotted holes

<table>
<tr><th rowspan="2">Bolt grade</th><th rowspan="2">Nominal structural bolt diameter</th><th colspan="3">Hole type in outer ply</th></tr>
<tr><th>Oversized</th><th>Short-slotted</th><th>Long-slotted</th></tr>
<tr><td>8.8
or equivalent strength</td><td>M12 to M36
1/2 inch to 1-1/2 inch
(12,7 mm to 38,1 mm)</td><td colspan="2" rowspan="2">Standard thickness hardened washer [a]</td><td rowspan="2">8 mm thick plate washer or continuous bar [b, c]</td></tr>
<tr><td rowspan="2">10.9
or equivalent strength</td><td>M12 to M24
½ inch to 1 inch
(12,7 mm to 25,4 mm)</td></tr>
<tr><td>M27 to M36
1-1/8 inch to 1-1/2 inch
(28,6 mm to 38,1 mm)</td><td colspan="2">8 mm thick hardened washer [a, b, d]</td><td>Hardened standard thickness washer with either a 10 mm thick plate washer or continuous bar [b, c]</td></tr>
<tr><td colspan="5">[a] This requirement shall not apply to heads of round head spline-drive bolt assemblies that provide a bearing circle diameter that meets the requirements of the applicable assembly standard.
[b] Multiple washers with a combined thickness of 8 mm or larger do not satisfy this requirement.
[c] The plate washer or bar shall be of structural-grade steel material, but need not be hardened.
[d] Alternatively, a 10 mm thick plate washer and an ordinary thickness hardened washer may be used. The plate washer need not be hardened.</td></tr>
</table>

When the torque control or combined method of pretensioning is used, the hardened washer as supplied or tested with the assembly shall be used under the turned element.

When the spline-drive twist-off bolt method of pretensioning is used, the hardened washer supplied with the assembly shall be used under the nut.

When the direct tension indicator method of pretensioning is used, a hardened washer shall be used as follows:

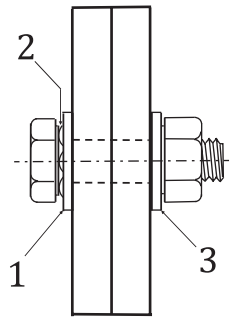
— when the nut is turned and the direct tension indicator is located under the nut, a hardened washer shall be used between the nut and the direct tension indicator - see Figure 3b);

— when the bolt head is turned and the direct tension indicator is located under the bolt head, a hardened washer shall be used between the bolt head and the direct tension indicator - see Figure 3c).

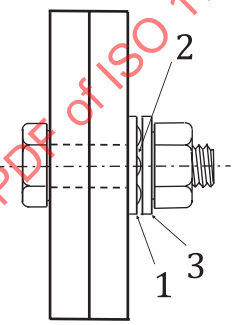
When the direct tension indicator method of pretensioning is used, a hardened washer is not required where:

— the nut is turned and the DTI is under the bolt head - see Figure 3a);

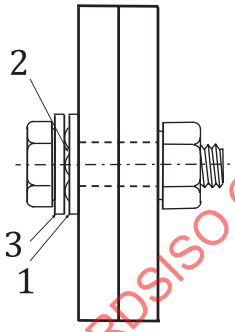
— the bolt head is turned and the DTI is under the nut - see Figure 3d).



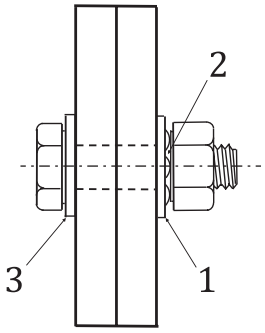
a) DTI under bolt head, nut turned



b) DTI under nut, nut turned



c) DTI under bolt head, bolt head turned



d) DTI under nut, bolt head turned

Key

1 direct tension indictor (DTI)
2 direct tension indictor gap measurement location
3 hardened steel washer

Figure 3 — Washer placement with direct tension indicators

7.2.8.3 Chamfered washers

When required by the product specification, the washers used under heads of pretensioned structural bolts shall be chamfered and positioned with the chamfer towards the bolt head. Washers used under nuts may be non-chamfered or chamfered.

7.2.8.4 Plate washers

Plate washers shall be used for connections with slotted and oversized holes as prescribed in Table 3.

For non-pretensioned structural bolting assemblies, the following may be used to adjust the grip length:

— One plate washer of any thickness; or

— Up to three plate washers, with a maximum combined thickness of 12 mm.

For pretensioned structural bolting assemblies, up to two plate washers may be used to adjust the grip length.

For non-pretensioned structural bolting assemblies, the plate washer or additional plate washers may be placed either on the side that is turned or on the side that is not turned.

For pretensioned structural bolting assemblies installed using any method except the torque control method, the plate washer or additional plate washers may be placed either on the side that is turned or on the side that is not turned.

For pretensioned structural bolt assemblies tightened by the torque control method, only one plate washer may be used on the side that is turned. Alternatively, the plate washer or additional plate washers may be placed on the side that is not turned.

Bolts detailed to have the threads excluded from the shear plane should be checked for conformance.

NOTE 1 Any use of additional washers or plate washers, or if plate washers of different thickness than specified are used, can result in the relocation of the shear plane.

Dimensions and steel grades of plate washers shall be specified in the execution specification. They shall not be thinner than 4 mm.

NOTE 2 For foundation bolts, see 6.2.2.4.

7.2.8.5 Taper washers

Taper washers shall be used if the surface of the constituent product is at an angle to a plane perpendicular to the bolt axis of more than that prescribed in Table F.5.

Dimensions and steel grades of taper washers shall be specified in the execution specification.

When regional or national standards are used, the use of taper washers shall meet the requirements of Table F.5.

7.2.9 Locking methods

Locking devices shall not be used with pretensioned assemblies unless required by the execution specification.

When locking devices are specified in addition to tightening, nuts shall be prevented from working loose by the use of locknuts, jam nuts, double nuts, thread burring, or other methods permitted by the execution specification.

Where a non-pretensioned joint is subject to impact or vibration, the effectiveness of the selected locking devices should be considered. See 5.2.9.

Welded joints should also be considered in lieu of bolted joints. Structural bolts and nuts shall not be welded.

The prohibition on welding of nuts does not apply to special weld nuts in accordance with, e.g. ISO 21670 or to weld studs.

7.3 Tightening of non-pretensioned bolts

Non-pretensioned structural bolts shall be brought to the snug tight condition, as a minimum.

Tightening structural bolts beyond the snug-tight condition shall not be cause for rejection.

NOTE The snug-tight condition is defined in ISO 17607-1.

7.4 Tightening of pretensioned bolts

7.4.1 Bolting procedure for pretensioned bolts

Prior to installation and tightening of pretensioned high-strength structural bolts, a bolting procedure for installation and tightening shall be prepared and shall indicate, as a minimum, the type of structural bolts and the tightening method.

Execution and supervision of bolt tightening work shall be carried out in accordance with the bolting procedure.

High-strength structural bolts for pretensioning shall be used without alteration to the as-delivered lubrication unless the direct tension indicator method, the turn-of-nut method, or a procedure developed using Annex N is adopted.

If the pretensioning process is delayed under uncontrolled exposure conditions such that the lubrication has degraded, and the direct tension indicator method or the turn-of-nut method is used, the performance of the lubrication should be checked and can be improved.

Before commencement of pretensioning, the connected components shall be fitted together and the structural bolts in a bolt group shall be tightened in accordance with 7.2, but the residual gap between connected components shall not exceed 1 mm with the necessary corrective action on steel components.

NOTE Generally, structural bolting assemblies used for achieving initial fit up need not be tightened to the minimum pretension or un-tightened and would therefore still be usable in the location in the final bolting up process. See 7.8.

Any of the pretensioning methods given in 7.4.7 through 7.4.11 may be used, unless restricted by the execution specification.

Tightening to the snug-tight condition and all steps of pretensioning shall be carried out progressively from the most rigid part of the joint to the least rigid part. To achieve uniform pretensioning, more than one cycle of tightening may be necessary.

7.4.2 Pretensioning tools

For the torque method, torque wrenches used in all steps of the method shall be capable of an accuracy of ±4 % in accordance with ISO 6789-1. Each wrench shall be maintained in accordance with ISO 6789-1, and in case of pneumatic wrenches, checked every time the hose length is changed.

For the combined method, torque wrenches used in the first step of the method shall be capable of an accuracy of ±10 % and checked yearly.

Other tightening equipment (e.g. hydraulic devices for axial pretensioning, ultrasonic control systems) shall be calibrated in accordance with the recommendations from the equipment manufacturer.

Pneumatic impact wrenches, if used, shall be of adequate capacity and supplied with sufficient air to perform the required pretensioning of each bolt within approximately 10 sec for bolts up to and including M30 diameter, and within approximately 15 sec for larger diameter bolts.

Checks shall be carried out after any incident affecting the wrench during use (e.g. significant impact, fall, overloading).

7.4.3 Minimum pretension

Unless specified in the execution specification, the nominal minimum pretension F_p is calculated in accordance with Formula (1):

$$F_p = 0{,}7\, f_{ub} \times A_s \tag{1}$$

where

f_{ub} is the nominal tensile strength of the bolt material;

A_s is the tensile stress area of the bolt.

When regional or national standards are used, the minimum pretension shall meet the requirements of Annex E.

This level of pretension shall be used for all slip-resistant joints and for all other pretensioned joints unless a lower level of pretension is specified in the execution specification. In the latter case, the structural bolt assemblies, the pretensioning method, the pretensioning parameters and the inspection requirements shall also be specified.

NOTE Pretension can be used for slip resistance, for seismic connections, for fatigue resistance, for execution purposes, or as a quality measure (e.g. for durability).

7.4.4 Bolting assembly k-class calibration

When specified, the *k*-class (as-delivered bolt calibration condition) of the structural bolting assembly shall be appropriate for the method used. As an alternative for all methods except the torque method, calibration to Annex H may be used. Annex H for bolt validation or evaluation for the torque method may be used if permitted by the execution specification.

The as-delivered calibration is valid for tightening by rotation of the nut. Tightening shall be performed by rotation of the nut except where the access to the nut side of the assembly is inadequate. If tightening is done by rotation of the bolt head, calibration shall be done in accordance with Annex H, by supplementary testing from the matched bolting assembly manufacturer, or in accordance with an applicable standard. Special precautions, depending on the tightening method adopted, may be necessary when bolts are tightened by rotation of the structural bolt head.

NOTE EN 14399-2 is an example of an applicable standard for calibration.

7.4.5 *k*-factor

The *k*-factor may be calculated in accordance with Formula (2):

$$k = \frac{M}{(F \times d)} \tag{2}$$

where

M is the applied tightening torque;

F is the achieved pretension;

d is the nominal diameter of the bolting assembly.

NOTE The *k*-factor covers the friction in the bearing surface between the nut and the washer and the friction factor between the nut and bolt threads. Variability in the surface condition of the manufactured threads and the bearing surface between nut and washer will affect the *k*-factor, and limits can be set for this variability in terms of the as-delivered calibration condition or *k*-class. If there is deterioration of the surface condition of the threads before installation, this will also change the value of the *k*-factor.

7.4.6 Pre-installation verification testing

For structural bolting assemblies in EXL2, EXL3, or EXL4, with no known *k*-class or a *k*-class of K0, the pre-installation verification testing procedure shall be the method provided in Annex G, unless otherwise restricted by the execution specification.

For EN 14399-3, EN 14399-4, and EN 14399-10 structural bolting assemblies with a *k*-class of K1 or K2, pre-installation verification testing is not required, unless specified in the execution specification.

7.4.7 Torque method

For pretensioning using the torque method, the bolting procedure shall be selected from the methods provided in Annex I, unless otherwise restricted by the execution specification.

7.4.8 Combined method

For pretensioning using the combined method, the bolting procedure shall be selected from the methods provided in Annex J, unless otherwise restricted by the execution specification.

NOTE The combined method is also known as the part-turn method.

7.4.9 Spline-drive twist-off method

For pretensioning using the spline-drive twist-off method, the bolting procedure shall be as provided in Annex K, unless otherwise restricted by the execution specification.

NOTE The spline-drive twist-off method is also known as the HRC method, Torshear method, and twist-off tension control bolt method.

7.4.10 Direct tension indicator method

For pretensioning using the direct tension indicator method, the bolting procedure shall be as provided in Annex L, unless otherwise restricted by the execution specification.

7.4.11 Turn-of-nut method

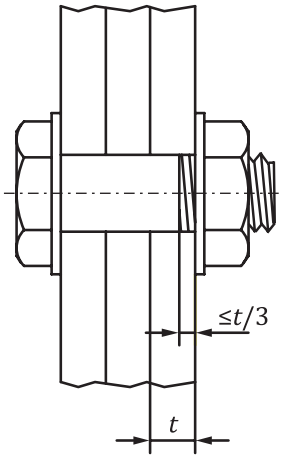
For pretensioning using the turn-of-nut method, the bolting procedure shall be selected from the methods provided in Annex M, unless otherwise restricted by the execution specification.

7.5 Fit bolts

Fit bolts may be used in pretensioned or non-pretensioned applications, and 7.3 or 7.4 applies, as appropriate, in addition to the requirements below.

The length of the threaded portion of the shank of the fit bolt (including thread run out) included in the bearing length should not exceed 1/3 of the thickness of the plate adjacent to the nut unless specified in the execution specification, see Figure 4.

Fit bolts shall be installed without applying excessive force, and in such a way that the thread is not damaged.



Key

t plate thickness

Figure 4 — Threaded portion of the shank in the bearing length for fit bolts

7.6 Temporary bolts

Temporary bolts are used for assembly of structural members during erection prior to full fastening or welding, to prevent deformation or collapse of the framework caused by external forces.

In typical high-strength structural bolted joints, temporary bolts shall be bolts or assemblies for either non-pretensioned applications (see Table B.1 through Table B.5) or pretensioned applications (see Table B.1 through Table B.3). The number of temporary bolts shall be approximately one third of the total number of bolts used in the final joint and shall not be less than two. Temporary bolts shall be located in a balanced distribution and shall be tightened as required for a non-pretensioned application.

Temporary bolts used for erection pieces for welded joints shall be high-strength bolts, and all bolts shall be tightened to at least the snug tight condition.

High-strength structural bolts used temporarily during erection to facilitate assembly may be used in the final connection, but if so used, they shall not be pretensioned until all bolts in the connection have been tightened to the snug-tight condition.

Temporary bolts that are to be removed shall be identified.

7.7 Loss of pretension

The potential loss of pretension from its initial value due to several factors, e.g. relaxation, creep of surface coatings (see Annex P and Annex Q), should be considered. In case of thick surface coatings, it shall be specified if measures shall be taken to offset possible subsequent loss of bolt pretension.

The higher levels of pretension normally achieved when using the combined method and the turn-of-nut method should be considered when evaluating the possible loss of pretension.

For the torque method, restoring the required pretension can be achieved by retightening after a delay of several days.

For the combined method and the turn-of-nut method, restoring the required pretension can be achieved by retightening, but caution is warranted to avoid excessive levels of pretension that would cause the bolting assembly to fail, and testing should be considered to verify that suitable pretension is achieved without undue damage to the bolt.

NOTE For significantly yielded bolts, there is no generally accepted procedure for retightening. Yielded bolts that require significant added nut rotation can cause the nut to engage and seize on the stretched bolt threads.

Restoring the required pretension by retightening is not considered a reuse.

7.8 Reuse of structural bolts

Touching up or retightening of structural bolts that may have been loosened by the installation of adjacent bolts shall not be considered to be a reuse. The bolt head or nut shall not be loosened except for the purpose of complete removal of the individual bolting assembly.

NOTE 1 Generally, bolting assemblies used for achieving initial fit up should not have been tightened to the minimum pretension or untightened, and therefore would still be usable in their location in the final bolting up process.

If a bolting assembly has been tightened to the minimum pretension and is later untightened, it shall be removed, and the assembly shall be discarded.

If permitted by the execution specification, uncoated structural bolts of product class 8.8 or equivalent strength and lower may be reused. Such reuse shall only be permitted once, only where the bolt remains in the same connection in which it was originally tensioned, and with the same grip. Structural bolts that have been pretensioned shall not be reused in another connection.

The following structural bolts shall not be reused:

a) uncoated structural bolts of product class 10.9 or equivalent tensile strength and higher;

b) spline-drive assemblies of any product class;

c) coated structural bolts of any product class;

d) bolts that have been damaged or distorted.

NOTE 2 As a guide, an uncoated structural bolt of product class 8.8 or equivalent strength and lower is suitable for reuse if the nut can be run up the full length of threads by hand.

7.9 Use of special fasteners

When the use of special structural bolting components is specified, they shall be used in accordance with the component manufacturer's recommendations or instructions, or both, and the appropriate provisions of 7.1 to 7.4.

NOTE 1 Examples of special structural bolting components include threaded studs, and bolts used in specially tapped holes.

Annex N may be used to develop installation procedures.

Any procedure tests required for use of special bolting components in non-pretensioned or pretensioned applications shall be specified.

a) Detailed installation instructions shall be available and can be prepared by the component manufacturer, an independent testing laboratory, or qualified entity in a supplemental specification, and, as a minimum, shall provide for the:

   1) pretensioning parameters (e.g. tightening torques, pretension level);

   2) required character and frequency of pre-installation verification;

   3) alignment of bolt holes to permit insertion of the special bolts without undue damage;

   4) placement of special bolts in all holes, including any washer requirements as appropriate;

   5) systematic assembly of the joint, progressing from the most rigid part of the joint until the connected plies are in firm contact;

6) subsequent systematic pretensioning of all special bolts in the joint, progressing from the most rigid part of the joint in a manner that will minimize relaxation of previously pretensioned bolts.

b) Detailed inspection instructions shall be available in a supplemental specification and, as a minimum, shall provide for:

1) observation of the required pre-installation verification testing;

2) subsequent routine observation to ensure the proper use of the special bolting components.

Specially tapped holes or threaded studs may be used as equivalent to the use of a bolting assembly in pretensioned and non-pretensioned assemblies provided that the materials, thread forms and thread tolerance conform with the respective product standard, and in case of pretensioning, sufficient tightening parameters can be developed by proof testing.

NOTE 2 EN 1090-2 provides information on the supply and use of resin injection bolts.

7.10 Galling and seizure of stainless-steel structural bolts

The following methods may be used to avoid galling problems:

a) anti-galling agents, e.g. an appropriate lubricant suitable for stainless steel;

b) dissimilar standard grades of stainless-steel structural bolt that vary in composition, work hardening rate and hardness (e.g. Grade A2-C4, A4-C4 or A2-A4 bolt-nut combination in accordance with ISO 3506-1 and ISO 3506-2);

c) in severe cases, a proprietary high work-hardening stainless-steel alloy structural bolt for one component or hard surface coatings applied, e.g. nitriding or hard chromium plating.

If dissimilar metals or coatings are used, it is necessary to ensure that the required corrosion resistance is obtained.

NOTE 1 Stainless-steel bolting products listed in ISO 3506-1 that include the identifier Lu immediately after the property class can provide a controlled torque/tension relationship.

NOTE 2 Galling can result from local adhesion and rupture of surfaces under load and in relative motion during fastening. In some cases, weld bonding and seizure can result.

NOTE 3 The greasing of bolts is beneficial but can result in contamination by dirt and can present problems for storage.

8 Inspection, testing, and correction

8.1 General

See ISO 17607-1.

8.2 Structural bolting inspection

8.2.1 Inspection prior to erection of steelwork

All connected plies shall meet the requirements in 6.3.

For slip-resistant connections, the friction surfaces shall be visually checked immediately before assembly. Acceptance criteria shall be in accordance with 6.4.

Nonconformities shall be corrected in accordance with 8.3.

All bolt holes shall meet the requirements in 6.2.

8.2.2 Inspection prior to installation of bolts

Prior to installation, structural bolting components shall be visually inspected by the installer for gross physical defects, including cracks, thread damage and loss of lubrication.

For pretensioned bolts in EXL2, EXL3, and EXL4, the tightening procedure shall be checked using a pre-installation verification test prescribed in 7.4.6.

8.2.3 Inspection after installation of bolts

All bolts shall be inspected for the following:

a) bolts are of the prescribed grade;

b) bolts are of the prescribed size;

c) bolts have sufficient but not excessive thread extending beyond the nut;

d) bolting assemblies have the prescribed locking device, if a locking device has been specified.

All connections shall be visually checked after they are bolted up with the structure aligned locally to ensure that they are properly packed in accordance with 7.2.2, and that the plies of the connected elements have been brought into firm contact. Acceptance criteria and action to correct nonconformity shall be in accordance with 7.2.1, 7.2.3 and 7.2.4.

If the nonconformity is due to differing ply thickness that exceeds the criteria specified in 7.2.2, the connection shall be remade. Otherwise, the nonconformity may be corrected, if possible, by adjusting the local alignment of the component.

Structural bolting assemblies shall be visually examined to ensure washers have been used as required. If chamfered washers are installed, they shall be visually checked to ensure that assembly is in accordance with 7.2.8.3. If direct tension indicators are used, the assembly shall be visually examined to ensure that it is in accordance with the relevant product standard or the manufacturer's written instructions, see 7.4.10.

Connections identified during inspection (punch list preparation) that do not have a full complement of bolts shall be checked for fit up after the missing bolts have been installed.

Corrected connections shall be checked again on re-completion.

8.2.4 Inspection of pretensioned bolts

8.2.4.1 General

The inspection method shall be selected from the methods provided in Annex O, unless otherwise restricted by the execution specification.

Pretensioning of bolts shall be periodically observed during installation to ascertain that the proper procedures are employed.

8.2.4.2 Inspection during and after pretensioning

For EXL2, EXL3, and EXL4, inspection during and after pretensioning shall be carried out as follows:

a) Inspection of either installed bolting assemblies or installation methods, or both, shall be undertaken depending on the pretensioning method used. The locations selected shall be on a random basis, ensuring that the sampling covers the following variables as appropriate - connection type, bolt group, fastener lot, type and size; equipment used, and the installation personnel.

b) For the purposes of the inspection, a bolt group is defined as bolting assemblies of the same origin in similar connections with the bolting assemblies of the same size and class. A large bolt group may be subdivided into subgroups for inspection purposes.

c) Connections shall be checked by visual inspection to ensure they have been properly packed, if required, and have achieved the snug-tight condition.

d) For final inspection, the same bolting assembly shall be used for checking both under-tensioning, and, if specified, over-tensioning when applying the torque method.

The criteria defining a nonconformity and requirements for corrective action are specified in 8.2.4.3 to 8.2.4.7 for each pretensioning method.

If bolting assemblies are not installed and pretensioned in accordance with the defined method, the removal and re-installation of the whole bolt group shall be witnessed.

8.2.4.3 Inspection of torque method

The inspection of a bolting assembly shall be carried out, using Table 4, by the application of a torque to the nut (or to the bolt head, if specified) using a calibrated torque wrench. The objective is to check that the nut does not initiate rotation when applying a torque of 1,05 times the torque value $M_{r,i}$ (i.e. $M_{r,2}$ or $M_{r,test}$). Caution shall be taken to keep any additional rotation to a strict minimum. The following conditions apply:

a) the torque wrench used for the inspections shall be correctly calibrated and have an accuracy of ±4 %, as shown on the calibration certificate;

b) the inspection shall be carried out between 12 h and 72 h after final completion of pretensioning in the bolt group concerned;

   If the bolting assemblies to be inspected are from different assembly lots, with inspection torque values that are different, the locations of each lot shall be established.

c) if the result is rejection, the accuracy of the torque wrench used for tightening shall be checked.

Table 4 — Inspection of pretensioning by the torque method

Execution Class	At start of pretensioning	After pretensioning
EXL2	Identification of assembly bolt lot locations	Inspection for under-tensioning, and, if specified, over-tensioning
EXL3 and EXL4	Identification of assembly bolt lot locations Checking the selection of the bolt pretensioning procedure for each bolt group	Inspection for under-tensioning, and, if specified, over-tensioning

A bolting assembly for which the nut turns by more than 15° by the application of the inspecting torque is considered to be under-tensioned (<100 %) and shall be retensioned up to the required torque.

If a check for over-tensioning is specified, the requirements shall be specified. Over-tensioned bolting assemblies shall be removed and discarded.

8.2.4.4 Inspection of combined method

For bolts installed using a combined method, the following additional inspections shall be carried out:

a) The torque wrench calibration reports shall be checked to verify the accuracy to 7.4.2.

b) It shall be ensured by routine observation that the bolting crew properly applies the calibrated wrench to the nut for the first step.

c) If the connections do not achieve the snug-tight condition in accordance with 7.2.1 and 7.2.2, the calibrations of the torque wrenches in combination with the applied loads shall be controlled by

supplementary tests to achieve the correct initial pre-tightening load. If necessary, the initial torque application has to be repeated with the corrected torque values. If still unpacked, the thickness and sloping surfaces of the assembled connections shall be inspected and adjusted.

d) For EXL3 and EXL4, the application of the initial torque application shall be checked before marking using the same torque conditions as used to reach the required initial bolt tension. If a nut turns by more than 15° by the application of the inspecting torque, it shall be retightened and all remaining bolts in the connection shall be checked.

e) Before the application of the required rotation starts, the markings of all the nuts relative to the bolt threads shall be visually inspected. Any mark missing shall be corrected.

f) It shall be ensured by routine observation that the bolting crew properly applies the installation wrench to the turned element.

After the application of the required rotation, the marks shall be inspected with the following requirements:

— if the rotation angle is more than 15° below the specified value, this angle shall be corrected;

— if the rotation angle is more than 30° over the specified angle, or the bolt or the nut has failed, the bolting assembly shall be replaced with a new assembly.

8.2.4.5 Inspection of spline-drive twist-off bolt method

For bolts installed using the spline-drive twist-off bolt method, the following additional inspections shall be carried out:

a) The inspection shall be carried out on the completed bolting assemblies by visual inspection. Pretensioned bolt assemblies are identified as those with the spline end sheared off. A bolt assembly for which the spline end remains is considered to be under-tensioned.

b) For EXL3 and EXL4, when location marks (matchmarks) are used, after the completion of pretensioning, regardless of any washer rotation, the nut rotation amount shall be visually inspected by making reference to marks made after the preliminary tightening. For each group of bolts, if a significant discrepancy is found in the amount of nut rotation, the nut rotation of all bolts in the group shall be measured and the average rotation angle shall be calculated. Bolts with rotation angles within ±30° of the average rotation angle shall be accepted. Rejected bolts shall be replaced.

If pretensioning of twist-off bolting assemblies is completed using another pretensioning method, they shall be inspected in accordance with the provisions for that method.

8.2.4.6 Inspection of direct tension indicator method

For bolts installed using the direct tension indicator method, the following additional inspections shall be carried out:

a) It shall be ensured by routine observation that the bolting crew properly applies the installation wrench to the turned element.

b) Prior to final pretensioning, it shall be ensured that the protrusions are properly oriented away from the work. It shall be ensured by routine observation that the appropriate feeler gauge would be accepted in at least the minimum permitted number of locations between the protrusions of the direct tension indicator. If the appropriate feeler gauge would be rejected in more than the maximum permitted number of locations, the bolting assembly and direct tension indicator shall be removed and replaced.

c) After final pretensioning, either:

1) the direct tension indicators shall be inspected using a feeler gauge to ensure that adequate deformation of the protrusions has been achieved in accordance with the manufacturer's installation procedures; or

2) it shall be ensured by routine observation that the appropriate feeler gauge would be rejected in at least the minimum required number of locations between the protrusions of the direct tension indicator. If the direct tension indicator has not been tightened to the specified limit, the assembly can be further tightened until this limit is achieved; or

3) if the direct tension indicator provides a visual indicating system, assemblies selected for inspection shall be checked to establish that the system indicates that the required pretension has been achieved, in accordance with the requirements in the relevant product standard or manufacturer's written instructions.

If the bolting assemblies are not installed in accordance with the relevant product standard or in accordance with the manufacturer's written installation procedures, the removal and reinstallation of the non-conforming assembly shall be supervised, and the whole bolt group shall then be inspected. If the direct tension indicator has not been pretensioned to the specified limit, the assembly can be further tensioned until this limit is achieved.

8.2.4.7 Inspection of turn-of-nut method

For bolts installed using a turn-of-nut method, the following additional inspections shall be carried out:

a) For EXL3 and EXL4, when location marks (matchmarks) are used, before the application of the required rotation starts, the markings of all the nuts relative to the bolt shall be visually inspected. Any marks missing shall be corrected.

b) It shall be ensured by routine observation that the bolting crew properly rotates the turned element relative to the unturned element by the amount specified in Table M.1 or Table M.2, as appropriate. Observation of the final nut rotation may be achieved by using marked wrench sockets or location marks. When bolting assemblies have permanent location marks after the initial fit-up and snugging of the joint but prior to pretensioning, visual inspection of the final location marks after pretensioning is permitted in lieu of routine observation.

8.2.5 Inspection of special structural fasteners and special methods

8.2.5.1 General

Requirements for inspection of connections using special structural fasteners, including stainless-steel fasteners, or special methods in accordance with 5.2.10 and 7.9 shall be specified.

If tapped holes are used in cast materials, non-destructive testing (NDT) around the tapped holes shall be carried out to ensure material homogeneity.

8.2.5.2 Other structural bolting components

Inspection of connections with other structural bolting components (e.g. hook-bolts, special fasteners) shall be applied in accordance with product standards or recommendations, manufacturers recommendations, or specified methods.

8.3 Correction

8.3.1 Excessive coating thickness

For pretensioned and slip-resistant joints, excessive coating thickness that can cause substantial loss of bolt pretension shall be removed or reduced in thickness before assembly, unless otherwise approved in the execution specification.

8.3.2 Replacement of structural bolting components and assemblies

Structural bolts, nuts and washers that, on visual inspection, show evidence of physical defects shall be replaced.

The bolting assembly shall be replaced when:

a) for spline-drive bolting assemblies, there is washer rotation with nut or structural bolt rotation;

b) when location marks (matchmarks) are used, a significant discrepancy is found in the nut rotation amount; or

c) the bolt length or orientation of the installed structural bolt is incorrect.

A pretension that is greater than the minimum value specified, in general, shall not be cause for rejection.

NOTE A pretension that is greater than the minimum value specified is beneficial for compensating for pretension losses.

9 Documents required to claim conformity to this document

9.1 General

Constructors may claim conformity with the requirements of this document either by:

— adoption of the ISO standards referenced in Clause 2; or

— adoption of other standards to those listed in Clause 2 that provide technically equivalent conditions; or

— adoption of other documents that provide technically equivalent conditions.

Unless otherwise listed in the execution specification, it is the responsibility of the constructor to demonstrate that the standards or documents selected provide technically equivalent conditions to those in the corresponding ISO standards.

Prior to execution, adoption of other standards or documents shall be verified and approved by the specifier and shall be incorporated into the execution specifications.

NOTE The contents of Annex B through Annex O do not establish that the standards or documents listed are technically equivalent, which remains the responsibility of the constructor.

9.2 Declaration of conformity

A constructor claiming conformity with these requirements shall list the applicable supporting standards or documents.

Annex A
(normative)

Additional information, list of options and requirements related to the execution levels

A.1 List of required additional information

Table A.1 provides the additional information that is required in the text of this document as appropriate to fully define the requirements for execution of the work to be in accordance with this document (e.g. where the wording "shall be specified" is used).

Table A.1 — Additional information required

Clause	Additional information required
4	**Execution specification and quality requirements**
4.2	Technically equivalent national standards and documents
4.2	Deviations from the requirements of this document
5	**Constituent products**
5.2.1	Property classes of bolts and nuts and, if appropriate, coatings, together with any required options within the product standard
5.2.2	Mechanical properties for carbon and alloy steel bolting assemblies with larger diameters than those specified in ISO 898-1, ISO 898-2 and ISO 898-3
5.2.2	Mechanical properties for austenitic or austenitic-ferritic stainless-steel bolting assemblies with larger diameters than those specified in ISO 3506-1 and ISO 3506-2, or those specified in other relevant national standards
5.2.2	Mechanical properties for atmospheric corrosion-resistant bolting assemblies
5.2.4.2	For taper washers, dimensions applicable to shape (see 7.2.8.3)
5.2.8	Chemical composition of the material of atmospheric corrosion-resistant structural bolting components
5.4.1	Properties for rods used as foundation bolts
5.4.2	For anchorage systems other than foundation bolts, if reinforcing steels or proprietary products shall be used
6	**Preparation and assembly**
6.2.1	Nominal clearances for pins not intended to act in fitted conditions
6.2.1	Dimensions for movement joints
6.2.2.4	For countersunk bolts, dimensions of the countersinking
6.4.2	For slip-resistant joints, the slip factor
6.4.2	Coating, if permitted in the slip surface
7	**Structural bolting**
7.2.1	Identify the joint type as a non-pretensioned joint, pretensioned joint, or slip-resistant joint
7.2.2	Locations where full contact bearing is required
7.2.6.1	If a nominal bolt diameter used for structural bolting is less than M12, the requirements associated with its use
7.2.6.2	Where bolts must have threads outside shear plane, the dimensions of the bolts.
7.2.6.2	Where bolts must have threads outside the shear plane, with connected parts of unequal thicknesses, the orientation of the bolt

Table A.1 *(continued)*

Clause	Additional information required
7.2.8.1	For non-pretensioned structural bolts, if washers are required with standard round holes, and if so, whether washers are to be placed under the nut or under the bolt head, whichever is to be rotated, or both.
7.2.8.2	For pretensioned structural bolts, if hardened washers are not required for Grade 8.8 or equivalent strength bolts, or are required under the unturned element
7.2.8.2	For pretensioned structural bolts, where hardened washers are required or not required for Grade 10.9 or equivalent tensile strength bolts
7.2.8.4	Dimensions and steel grades of plate washers, where used
7.2.8.5	Dimensions and steel grades of taper washers, where used (see 5.2.4.1)
7.2.9	Where locking devices are required with pretensioned assemblies
7.9	When required, procedure tests for use of special bolting components in non-pretensioned or pretensioned applications
8	**Inspection, testing, and correction**
8.2.4.1	Where pretensioned stainless-steel bolting assemblies are used, the requirements for inspection and testing
8.2.4.2	When the torque method has been used, if final tightening inspection includes checking for over-tightening (see 8.2.4.3)
8.2.4.3	If checking for over-tightening, the requirements (see 8.2.4.2)
8.2.5.1	Requirements for inspection of connections using special structural fasteners or special methods
8.2.5.2	Inspection method for connections with other structural bolting components, if required
9	**Documents required to claim conformity to these requirements**
9.1	List standards or documents selected that provide technically equivalent conditions to those in the corresponding ISO standards
9.1	When adopted by the constructor, verify and approve adoption of other standards or documents and incorporate into the execution specifications.

A.2 List of options

Table A.2 lists the items which may be specified in the execution specification to define requirements for the execution of the work where options are given in this document.

Table A.2 — List of options to be specified

Clause	Option(s) to be specified
5	**Constituent products**
5.2.3	If stainless-steel bolts may be used in pretensioned applications
5.2.6	If alternative direct tension indicators other than those listed in Table B.6 may be used
5.2.9	If devices that effectively prevent loosening or loss of pretension required are required
5.2.9	If prevailing torque nuts may be used as locking devices
5.2.10	If special structural fasteners may be used
5.2.15	If reconditioning of spline-drive assemblies and bolting components installed using the torque method may be performed by other than the manufacturer or supplier
5.4.1	If reinforcing steels may be used for foundation bolts
5.4.1	If reinforcing steels are used for foundation bolts, the grade of steel
6	**Preparation and assembly**
6.2.1	Nominal clearances for bolts if other than Table C.1
6.2.2	The dimensions of bolt holes if other than that provided by the nominal clearances

Table A.2 *(continued)*

Clause	Option(s) to be specified
6.2.2.2	If short-slotted holes can be used
6.2.2.2	If long-slotted holes can be used
6.5	For pretensioned and slip-resistant joints, if excessive coating thickness that can cause substantial loss of bolt pretension need not be removed or reduced in thickness before assembly
7	**Structural bolting**
7.2.2	If shims other than those made of flat steel are permitted
7.2.2	If shims are required to meet a specified friction slip factor
7.2.6.3	For non-pretensioned structural bolts, if less than one full thread in the grip is permitted, or if more than one thread in the grip is required (see Table F.3)
7.2.6.3	For pretensioned structural bolts, if less than two threads in the grip is permitted, or if more than two threads in the grip is required (see Table F.1)
7.2.6.4	If less than one thread protrusion beyond the outer face of the nut is permitted (see Table F.2 and Table F.4)
7.2.9	If other methods can be used for locking devices
7.4.1	If any of the pretensioning methods given in 7.4.7 through 7.4.11 are not permitted
7.4.3	If a nominal minimum pretension other than F_p is to be used
7.4.3	If a pretension less than F_p is specified, the pretensioning method, the pretensioning parameters and the inspection requirements
7.4.4	If a k-class is required for a bolting assembly
7.4.4	If Annex H for bolt calibration for the torque method may be used
7.4.6	If the selection of pre-installation verification testing procedure from Annex G is restricted
7.4.6	If pre-installation verification testing is required for EN 14399 structural bolting assemblies with a k-class of K1 of K2
7.4.7	If the selection of torque method provided from Annex I is restricted
7.4.8	If the selection of combined method provided from Annex J is restricted
7.4.9	If the use of the spline-drive twist-off method from Annex K is restricted
7.4.10	If the use of the direct tension indicator method from Annex L is restricted
7.4.11	If the selection of turn-of-nut method provided from Annex M is restricted
7.5	For fit bolts, if the threads may exceed 1/3 of the thickness of the plate from the outside surface on the nut side
7.7	If measures shall be taken to offset possible subsequent loss of bolt pretension (see Annex Q)
7.8	If uncoated structural bolts of product class 8.8 or equivalent strength and lower may be reused
8	**Inspection, testing, and correction**
8.2.4.1	If the selection of inspection method provided from Annex O is restricted
8.2.4.3	When performing inspection of the torque method, if application of a torque to the bolt head is required
Annex C	**Nominal hole clearances for bolts**
Table C.1	For applications such as towers and masts, if the clearance for normal round holes need not be reduced
Table C.2	For bolts of diameter 27 mm or greater, if the clearance is to be reduced from 3 mm to 2 mm
Annex F	**Threads in grip, thread protrusion, and use of taper washers**
	(see 7.2.6, 7.2.6.4, and 7.2.8.5)
Annex H	**Calibration test for EN 14399 pretensioned bolts under site conditions**
	(see 7.4.6)
H.8	If not stated in the manufacturer's instructions, values for deformations of the direct tension indicator protrusions
Annex J	**Pretensioning bolting assemblies — Combined method**

Table A.2 *(continued)*

Clause	Option(s) to be specified
J.1	If the use of values other than Table J.1 are to be used
J.3	If location marks (matchmarks) are required
Annex K	**Pretensioning bolting assemblies — Spline-drive twist-off method**
	If a mark running across the structural bolt, nut, washer and member is required
	If tightening is permitted using an alternative pretensioning procedure
	If the *k*-class if limited to *k*-class K0, K1and K2 with HRD nuts, or *k*-class K2 with HR nuts
Annex M	**Pretensioning bolting assemblies — Turn-of-nut method**
M.1	If location marks (matchmarks) shall be established after snug tightening,
Annex N	**Bolt tightening qualification procedure (BTQP)**
N3.1	If tightening shall be carried out by a method other than rotation of the nut
N3.3	If a component of a test assembly is permitted to be used more than once
N3.5	If tightening shall be carried out by a method other than rotation of the nut
Annex O	**Method for structural bolting inspection**
O.2	If shop inspection for EXL2 is required
Annex P	**Test to determine slip factor**
P.3	If it is required to estimate bolt pretension losses over time
P.5	If, for the "displacement - log time" curve, the design life of the structure is taken as other than 50 years

A.3 Requirements related to the execution levels

This clause lists requirements specific to each of the execution levels referenced in this document.

Items identified in bold letters in Table A.3 relate to the general system of control of execution and are amenable to a common choice of execution level across the whole of the structural steelwork (or a phase of the structural steelwork). The other items generally demand the selection of the appropriate execution level on a component–by-component or a connection detail-by-detail basis.

Table A.3 — Requirements for each execution level

Clauses	EXL1	EXL2	EXL3	EXL4
4 - Execution specification and quality requirements				
See ISO 17607-1				
5 – Constituent products				
5.1 General				
Inspection documents	See 5.1.2, Table 1 and Table 2			
5.2 Structural bolting products				
Identification and marking	See 5.2.13			
Traceability	—	See ISO 17607-1		
7 - Structural bolting				
7.2.2	—		if welding is used to secure shims, welding in accordance with ISO 17607-5.	
8 - Inspection, testing, and correction				
8.2.2 Inspection prior to installation of bolts				
Key A dash "—" indicates no specific requirement in the text.				

Table A.3 *(continued)*

Clauses	EXL1	EXL2	EXL3	EXL4
8.2.2	—	tightening procedure checked using a pre-installation verification test		
8.2.4 Inspection of pretensioned joints				
8.2.4.2	—	inspection during and after pretensioning		
Annex O - Method for structural bolting inspection				
O.1 **Sequential inspection method**				
O.1.1	—	number of bolting assemblies inspected in first step and second step, overall in the structure		
O.1.1	—	sequential type A		sequential type B
O.2 **Frequency inspection method based on execution level**				
	See Table O.1			
Key A dash "—" indicates no specific requirement in the text.				

Annex B
(normative)

Bolting component, assembly and coating standards

B.1 General

Tables B.1 to B.9 show the regional and national standards and documents corresponding to the ISO standard(s) referenced in this document.

A dash "—" in the tables below indicates no specific standard is applicable.

NOTE The contents of Tables B.1 to B.9 do not establish any technical equivalence between the standards and documents listed.

Table B.1 — Structural bolting assemblies for pretensioned and non-pretensioned applications

ISO standard(s) and documents referenced in this document	None
EN	EN 14399-1 EN 14399-2 EN 14399-3 EN 14399-4 EN 14399-7 EN 14399-8
AS/NZS	AS/NZS 1252.1 AS/NZS 1559
GB	GB/T 1231 GB/T 16939
GOST	GOST 1759.0 GOST 7796 GOST 7798 GOST 7805 GOST 7817 GOST 15589 GOST 32484.1 GOST 32484.3 GOST 32484.4 GOST R 50791
JIS/JSS	JIS B 1186
ASTM	—

Table B.2 — Spline-drive structural bolting assemblies for pretensioned and non-pretensioned applications

ISO standard(s) and documents referenced in this document	None
EN	EN 14399-10
AS/NZS	—
GB	GB/T 632 GB/T 633
GOST	GOST 32484.1 GOST 32484.4
JIS/JSS	JSS II 09
ASTM	ASTM F3125/F3125M, grade F1852 ASTM F3125/F3125M, grade F2280 ASTM F3148

Table B.3 — Structural components and related standards for pretensioned and non-pretensioned applications

	Bolts	**Nuts**	**Washers**
ISO standard(s) and documents referenced in this document	ISO 898-1[a,b]	ISO 898-2[a,b]	ISO 898-3[b] ISO 7089 ISO 7090 ISO 7091 ISO 7092 ISO 7093-1 ISO 7093-2 ISO 7094
EN	—	—	EN 14399-5 EN 14399-6
AS/NZS	—	—	—
GB		GB/T 229	GB/T 230
GOST	—	—	GOST 32484.5 GOST 32484.6
JIS/JSS	—	—	—
ASTM	ASTM F3125/F3125M grades A325, A325M, A490, A490M ASTM A354, grades BC, BD ASTM A449	ASTM A563/A563M grades C3, D, DH, DH3	ASTM F436/F436M

[a] Bolts with property class above 10.9 and nuts with property class above 10 are excluded.

[b] The product standard or specification shall ensure full loadability.

Table B.4 — Structural bolting assemblies for non-pretensioned applications only

ISO standard(s) and documents referenced in this document	None
EN	EN 15048-1 EN 15048-2
AS/NZS	—
GB	—
GOST	GOST 23118 STO NOSTROY 2.10.76
JIS/JSS	—
ASTM	None

Table B.5 — Structural components for non-pretensioned applications only

	Bolts	**Nuts**	**Washers**
ISO standard(s) and documents referenced in this document	ISO 4014[a] ISO 4017[a]	ISO 4032[a] ISO 4033[a]	—
EN	—	—	—
AS/NZS	AS 1110.1 AS 1111.1	AS 1112 (all parts)	AS 1237
GB	GB/T 5780 GB/T 1228	GB/T 41 GB/T 6177	—
GOST	—	—	GOST 18123
JIS/JSS	JIS B 1180	JIS B 1181	JIS B 1251 JIS B 1256
ASTM	ASTM A307	ASTM A563/A563M, grades A, B	ASTM F844

[a] Bolts with property class above 10.9 and nuts with property class above 10 are excluded.

Table B.6 — Direct tension indicators

ISO standard(s) and documents referenced in this document	None
EN	EN 14399-9
AS/NZS	—
GB	—
GOST	—
JIS/JSS	—
ASTM	ASTM F959/F959M

Table B.7 — Stainless-steel bolting components

	Bolts	Nuts	Washers
ISO standard(s) and documents referenced in this document	ISO 3506-1[a,b]	ISO 3506-2[b]	
EN	—		
AS/NZS	—		
GB	—		
GOST	GOST 7798 GOST 7805		
JIS/JSS	—		
ASTM	ASTM A193/A193M ASTM A320/ A320M ASTM F593 ASTM A1082/A1082M	ASTM A194 ASTM F594	

[a] Bolts of property class 100 or higher shall be treated as special fasteners.

[b] The product standard or specification shall ensure full loadability.

Table B.8 — Foundation bolts

ISO standard(s) and documents referenced in this document	None
EN	—
AS/NZS	—
GOST	GOST 24379.0 GOST 24379.1
GB	—
JIS/JSS	JIS B 1220
ASTM	ASTM F1554

Table B.9 — Coatings for bolting assemblies, bolts, nuts, washers, and direct tension indicators

	Hot dip galvanizing	Mechanical galvanizing	Electroplating	Thermal diffusion/ sherardizing	Zinc-flake coatings
ISO standard(s) and documents referenced in this document	ISO 1461 [a] ISO 10684		ISO 4042[b]	ISO 14713-3	ISO 10683
EN	—	—	—	—	—
AS/NZS	—	—	—	—	—
GB	—	—	—	—	—
GOST	GOST 9.307	—	—	GOST 28844	—
JIS/JSS	—	—	—	—	—
ASTM	ASTM F2329	ASTM B695		ASTM A1059	ASTM F1136 ASTM F2833 ASTM F3393

[a] ISO 1461 does not apply to hot dip galvanized products (e.g. fasteners) for which specific standards exist and which can include additional requirements or requirements which are different from those of ISO 1461.

[b] For bolts of property class 10.9 or with equivalent or higher tensile strength, electroplated coatings shall not be used.

Annex C
(normative)

Nominal hole clearances for bolts

Annex C provides nominal hole clearances used to establish the appropriate hole size. See 6.2.

Tables C.1 to C.4 show the nominal hole clearances from regional and national standards and documents corresponding to the ISO standard(s) referenced in this document, as indicated in the NOTE to each table.

Table C.1 is based on EN 1090-2:2018.

Table C.2 and Table C.3 are based on AISC 360-16 and CSA S16-19.

Table C.4 is based on Japan Building Standard Law, except for clearances used for bridges.

Table C.5 is based on SP 16.13330.

Table C.6 is based on GOST 11284.

NOTE The contents of Tables C.1 to C.5 do not establish any technical equivalence between the standards and documents listed.

Table C.1 — Nominal hole clearances for bolts

Dimensions in millimetres

Nominal bolt diameter *d*	**M12**	**M14**	**M16**	**M18**	**M20**	**M22**	**M24**	**M27 to M36**
Normal round holes [a]	1 [b,c]		2					3
Oversized round holes	3		4				6	8
Short-slotted holes (on the length) [d]	4		6				8	10
Long-slotted holes (on the length) [d]	1,5 *d*							

[a] For applications such as towers and masts the nominal clearance for normal round holes shall be reduced by 0,5 mm unless specified in the execution specification.

[b] For coated bolting assemblies, 1 mm nominal clearance can be increased by the coating thickness of the bolting assembly.

[c] Bolts with nominal diameter 12 mm and 14 mm, or countersunk bolts may also be used in 2 mm clearance holes

[d] For bolts in slotted holes the nominal clearances across the width shall be the same as the clearances on diameter specified for normal round holes.

NOTE Table C.1 is based on EN 1090-2:2018.

Table C.2 — Nominal hole clearances for bolts

Dimensions in millimetres

Nominal bolt diameter *d*	M12	M14	M16	M18	M20	M22	M24	M27 to M36
Normal round holes	2							3
Oversized round holes	4						6	8
Short-slotted holes (on the length) [a]	6						8	10
Long-slotted holes (on the length) [b]	1,5 *d*							

[a] For bolts in slotted holes the nominal clearances across the width shall be the same as the clearances on diameter specified for normal round holes.

[b] For bolts of diameter 27 mm or greater, the clearance shall be reduced from 3 mm to 2 mm when required by the execution specification.

NOTE Table C.2 is based on AISC 360-16 and CSA S16-19.

Table C.3 — Nominal hole clearances for bolts (non-metric units)

Dimension in inches

Nominal bolt diameter *d*	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
Normal round holes	1/16				1/8				
Oversized round holes	1/8	3/16			1/4	5/16			
Short-slotted holes (on the length) [a]	3/16	1/4			5/16	3/8			
Long-slotted holes (on the length) [a]	1,5 *d*								

[a] For bolts in slotted holes, the nominal clearances across the width shall be the same as the clearances on diameter specified for normal round holes.

NOTE Table C.3 is based on AISC 360-16 and CSA S16-19.

Table C.4 — Nominal hole clearances for bolts

Dimensions in millimetres

Nominal bolt diameter *d*	M12	M14	M16	M18	M20	M22	M24	M27 to M36
Normal round holes with pre-tensioned bolts	2							3[a]
Normal round holes with non-pretensioned bolts	1,0				1,5			

[a] 2,5 for bridge structures (outside the scope of Japan Building Standard Law).

NOTE Table C.4 is based on Japan Building Standard Law.

Table C.5 — Nominal hole clearances for bolts

Dimensions in millimetres

Bolt accuracy class and application conditions	Clearance
bolts of accuracy class A	0
bolts of accuracy class B in the construction of poles for overhead power lines, open switchgear and contact networks of transport	1
other cases	1, 2, or 3[a]

[a] Nominal hole diameter should be 2 mm to 3 mm larger than the nominal diameter of the bolt.

NOTE Table C.5 is based on SP 16.13330.

Table C.6 — Nominal hole clearances for bolts

Dimensions in millimetres

Nominal bolt diameter *d*	M12	M14	M16	M18	M20	M22	M24	M27	M30	M33	M36
1 row of holes	1										
2 rows of holes	2							3			
3 rows of holes	3				4			5			6

NOTE Table C.6 is based on GOST 11284.

Annex D
(normative)

Bolted friction surface slip factors

Annex D provides slip factors that may be used for friction surfaces in slip-resistant joints. See 6.4.

Table D.1 shows the regional and national standards and documents. There are no corresponding ISO standards referenced in this annex.

NOTE The contents of Table D.1 do not establish any technical equivalence between the standards and documents listed.

Table D.1 — Slip factors that may be used for friction surfaces

Designated standard and friction surface	Class (for designated standard)	Slip factor
EN 1090-2:2018		
Surfaces blasted with shot or grit with loose rust removed, not pitted	A	0,50 [a]
Surfaces hot dip galvanized to ISO 1461 and flash (sweep) blasted [b] and with alkali-zinc silicate paint with a nominal thickness of 60 µm [c]	B	0,40 [a]
Surfaces blasted with shot or grit: a) coated with alkali-zinc silicate paint with a nominal thickness of 60 µm [c]; b) thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80 µm.	B	0,40 [a]
Surfaces hot dip galvanized to ISO 1461 and flash (sweep) blasted (or equivalent abrasion method) [b]	C	0,35 [a]
Surfaces cleaned by wire-brushing or flame cleaning, with loose rust removed	C	0,30 [a]
Surfaces as-rolled	D	0,20 [a]
AISC 360-16, AISC 348-20		
Unpainted blast-cleaned steel surfaces	B	0,50
Surfaces with Class B coatings on blast-cleaned steel		
Unpainted clean mill scale steel surfaces	A	0,30
Surfaces with Class A coatings on blast-cleaned steel		
Hot-dipped galvanized surfaces, with or without hand wire brushing		
CSA S16-19		
Unpainted blast-cleaned steel surfaces	B	0,52
Surfaces with Class B coatings on blast-cleaned steel		
Metallized surfaces	D	0,45
Hot-dip galvanized surfaces	C	0,30
Unpainted clean mill scale steel surfaces	A	0,30
Surfaces with Class A coatings on blast-cleaned steel		
JASS 6:2018		

[a] The potential loss of preloading force from its initial value is considered in these slip factor values.

[b] Unless alternative equivalent abrasion process capability can be demonstrated, flash (sweep) blasting of hot dip galvanized surfaces shall be carried out according to the procedures and conditions set out in EN 15773. After flash (sweep) blasting the appearance of a matt surface indicates that a soft surface layer of un-alloyed zinc has been removed.

[c] Dry thickness to be within 40 µm to 80 µm range.

Table D.1 *(continued)*

Designated standard and friction surface	Class (for designated standard)	Slip factor
Surfaces treated by removing mill scale from the entire extent of the contact interface, kept open to the air so that red rust is spontaneously generated		0,45
Surfaces shot or grit blasted, with roughness values of not less than 50 µm R_z		0,45
Hot-dip galvanized surfaces lightly blasted after galvanizing, with the surface roughness not less than 50 µm R_Z		0,40
JGJ 82-2011		
Surface with shot or grit blasted	A	0,45
Surface with grit blasted and spray-metalized with an aluminium or zinc-based product	B	0,45
Surface with grit blasted and coated with zinc-based paint	C	0,40
Clean surface or rust cleaned with brush	D	0,30
AS 4100:2020, NZS 3404 Part 1:1997		
Clean as-rolled surfaces		0,35
GOST SP 16.13330		
Surfaces treated by shot blasting or grit blasting (two surfaces without conservation)		0,58
Flame treated surfaces (two surfaces without conservation)		0,42
Surfaces treated with steel brushes (two surfaces without preservation)		0,35
Surfaces without treatment		0,25

[a] The potential loss of preloading force from its initial value is considered in these slip factor values.

[b] Unless alternative equivalent abrasion process capability can be demonstrated, flash (sweep) blasting of hot dip galvanized surfaces shall be carried out according to the procedures and conditions set out in EN 15773. After flash (sweep) blasting the appearance of a matt surface indicates that a soft surface layer of un-alloyed zinc has been removed.

[c] Dry thickness to be within 40 µm to 80 µm range.

Annex E
(normative)

Nominal minimum pretension

Annex E provides nominal minimum pretensions that may be used for pretensioned and slip-resistant joints. See 7.4.3.

Table E.1 is based on EN 1090-2:2018, JASS 6:2018, AISC 360-16, CSA S16-19, AS/NZS 5131:2016, and STO NOSTROY 2.10.76-2012, as indicated in the NOTE to each table.

Table E.2 is based on AISC 360-16 and CSA S16-19.

Table E.3 is based on DASt-Richtlinie 024, Tightening screwed connections of dimensions M12 to M36, Stahlbau-Verlagsgesellschaft MbH.

NOTE The contents of Tables E.1 through E.3 do not establish any technical equivalence between the standards and documents listed.

Table E.1 — Nominal minimum pretension (kN) – metric bolts

Applicable standard/ Property class	Designation/Bolt diameter mm							
	M12	M16	M20	M22	M24	M27	M30	M36
8.8	47	88	137	170	198	257	314	458
10.9	59	110	172	212	247	321	393	572
JIS B 1186 F10T	62,6	117	182	226	262	341	417	—
ASTM F3125 grade A325M	—	91	142	176	205	267	326	475
ASTM F3125 grade A490M	—	114	179	221	257	334	408	595
AS/ NZS 1252.1 Grade 8.8	—	95	145	—	210	—	335	490
AS/ NZS 1252.1 Grade 10.9	—	130	205	—	295	—	465	680
STO NOS-TROY 2.10.76 Grade 8.8	49	91	142	—	—	—	—	—
STO NOS-TROY 2.10.76 Grade 10.9	—	118	184	229	266	346	423	—

NOTE Based on EN 1090-2:2018, JASS 6:2018, AISC 360-16, CSA S16-19, AS/NZS 5131:2020, and STO NOSTROY 2.10.76-2012.

Table E.2 — Nominal minimum pretension (kN) – non-metric bolts

Applicable standard/ Property class	Bolt diameter inch								
	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
ASTM F3125 grades A325 and F1852	54	85	125	173	227	285	361	432	523
ASTM F3125 grades A490 and F2280	67	107	156	218	285	356	454	538	658
NOTE Based on AISC 360-16 and CSA S16-19.									

Table E.3 — Nominal pretension $F_{p,C}$* (kN) – metric bolts

Property class	Designation/Bolt diameter mm							
	M12	M16	M20	M22	M24	M27	M30	M36
10.9	50	100	160	190	220	290	350	510
NOTE Based on DASt-Richtlinie 024, Tightening screwed connections of dimensions M12 to M36, Stahlbau-Verlagsgesellschaft MbH.								

Annex F
(normative)

Threads in grip, thread protrusion, and use of taper washers

Annex F provides requirements for threads in grip, thread protrusion, and use of taper washers. See 7.2.6.3, 7.2.6.4 and 7.2.8.5.

Tables F.1 through F.5 show the requirements of regional and national standards and documents. A default requirement is provided in each table.

NOTE 1 The contents of Tables F.1 through F.5 do not establish any technical equivalence between the standards and documents listed.

NOTE 2 For bolts under tensile loading, the likelihood of thread failure, instead of bolt fracture, can be reduced by increasing the number of threads in the grip.

Table F.1 — Minimum threads in the grip for pretensioned bolts

Unless otherwise specified	2 threads unless otherwise stated in the execution specification
AS/NZS 5131:2016	One thread plus the thread runout after snug tightening
NZS 3404, Part 1:1997	(i) Five threads for a bolt length up to and including 4 diameters (ii) Seven threads for a bolt length over 4 diameters but not exceeding 8 diameters (iii) Ten threads for a bolt length over 8 diameters
EN 1090-2:2018	EN 14399-3, EN 14399-7 and EN 14399-10, at least four full threads (in addition to the thread run out) shall remain clear between the bearing surface of the nut and the unthreaded part of the shank
	EN 14399-4 and EN 14399-8, at least two full threads (in addition to the thread run out) shall remain clear between the bearing surface of the nut and the unthreaded part of the shank
JASS 6:2018	Not stated, bolt length shall be specified in the execution specification
JARA	None stated
AISC 360-16	None stated
AASHTO 2017	three threads recommended
CSA S16-19	None stated

Table F.2 — Minimum thread protrusion for pretensioned bolts

Unless otherwise specified	1 thread protrusion, unless otherwise stated in the execution specification
AS/NZS 5131:2016	1 thread protrusion after snug tightening
NZS 3404, Part 1	1 thread protrusion after snug tightening
EN 1090-2:2018	1 thread pitch (p) protrusion
JASS 6:2018	1 thread
JARA	No protrusion required
AISC 360-16	Bolt end flush with or protruding beyond face of nut
CSA S16-19	Bolt end flush with or protruding beyond face of nut

Table F.3 — Minimum threads in the grip for non-pretensioned bolts

Unless otherwise specified	1 thread unless otherwise stated in the execution specification
AS/NZS 5131:2016	one clear thread run out shall be clear beneath the nut after tightening
NZS 3404, Part 1:1997	one clear thread run out shall be clear beneath the nut after tightening
EN 1090-2:2018	one clear thread run out shall be clear beneath the nut
JASS 6:2018	Not stated, bolt length shall be specified in the execution specification
AISC 360-16	None stated
AASHTO:2017	three threads recommended
CSA S16-19	None stated

Table F.4 — Minimum protrusion for non-pretensioned bolts

Unless otherwise specified	1 thread protrusion, unless otherwise stated in the execution specification
AS/NZS 5131:2016	at least one clear thread shall show above the nut after tightening
NZS 3404, Part 1:1997	at least one clear thread shall show above the nut after tightening
EN 1090-2:2018	1 thread pitch (p) protrusion
JASS 6:2018	3 threads stickout, unless otherwise stated in the execution specification
AISC 360-16	Bolt end flush with or protruding beyond face of nut
AASHTO:2017	
CSA S16-19	Bolt end flush with or protruding beyond face of nut
CSA S6-19	

Table F.5 — Taper washer use

Unless otherwise specified	Suitable tapered washer required when slope exceeds 1:20, non-rotating part placed against tapered washer
AS/NZS 5131:2016	Suitable tapered washer required when slope exceeds 1:20, non-rotating part placed against tapered washer
EN 1090-2:2018	1/20 (3°) for bolts with d ≤ 20 mm 1/30 (2°) for bolts with d > 20 mm
Japan	Suitable tapered washer required when slope exceeds 1:20, non-rotating part placed against tapered washer
AISC 360-16	ASTM F3125, all Grades, use 1:20 tapered washer for bolts when slope exceeds 5 % (1:20, approx. 3°)
AASHTO:2017	
CSA S16-19	ASTM F3125 Grades A325, A325, F1852, use 1:20 tapered washer if slope exceeds 5 % (1:20, approx. 3°) ASTM F3125 Grades A490, A490M, F2280, use tapered washer to match any slope
CSA S6-19	

Annex G
(normative)

Pre-installation verification testing for pretensioned bolting assemblies

This annex provides a test method to verify, prior to installation, that the bolting assemblies and installation procedures will perform as required.

NOTE This pre-installation verification testing method is based up AISC 348-20.

The purpose of the testing is to:

— confirm the suitability of the complete bolting assembly, including lubrication, for pretensioned installation;

— confirm the procedure and proper use by the bolting crew of the pretensioning method to be used.

A bolt tension measurement device shall be used where bolts are to be installed in pretensioned joints and slip-resistant joints.

The accuracy of a bolt tension measurement device shall be confirmed through calibration at least annually.

A representative sample of not fewer than three complete bolting assemblies of each combination of diameter, length, grade and lot to be used in the work shall be checked at the site of installation in a bolt tension measurement device to verify that the pretensioning method develops a pretension that is at least 5 % greater than that specified in Annex E. Washers shall be used in the pre-installation verification assemblies as required in the work.

If the actual pretension developed in any of the bolting assemblies is less than that specified in Annex E, the cause(s) shall be determined and resolved before the bolting assemblies are used in the work. Cleaning, lubrication and retesting of the bolting assemblies is permitted when the direct tension indicator method or the turn-of nut-method is used, provided that all assemblies are treated in the same manner. Relubrication is not permitted when the torque method, combined method, twist-off bolt method, or calibrated wrench method is used, except as prescribed in 5.2.15.

Annex H
(normative)

Calibration test for the EN 14399 series pretensioned bolts under site conditions

H.1 General

This annex specifies a test intended to represent site conditions to calibrate high-strength bolting assemblies for pretensioned bolted connections.

The purpose of the test is to determine the necessary parameters to ensure that the minimum required pretension is reliably obtained by the pretensioning methods specified for the EN 14399 series bolting assemblies.

This test is not to be used when the torque pretensioning method is used for EN 14399-3, EN 14399-4, EN 14399-7, or EN 14399-8 bolting assemblies, unless permitted in the execution specification.

The purpose of this test is not to upgrade the properties of a bolting assembly declared in accordance with EN 14399-1.

H.2 Symbols and units

See Table H.1.

Table H.1 — Symbols and units

Symbol	Definition	Units
A_s	nominal stress area of the bolt	mm^2 [a]
e_M	allowable ratio ($e_M = (M_{max} - M_{min})/M_m$)	–
F_b	bolt force determined during the test	kN
F_m	mean value of the i number $F_{b,I}$ test values for F_b	kN
$F_{p,C}$	required pretension of 0,7 f_{ub} As	kN
f_{ub}	nominal bolt strength (R_m)	MPa
M_i	individual value of the torque related to $F_{p,C}$,	Nm
M_m	mean value of the i number M_i values	Nm
M_{max}	maximum value of the i number M_i values	Nm
M_{min}	minimum value of the i number M_i values	Nm
$M_{r,test}$	torque reference value	Nm
s_M	estimated standard deviation of the i number M_i values	kN
V_M	coefficient of variation of the i number M_i values	–
V_F	coefficient of variation of the i number $F_{b,i}$ values	–
θ_{pi}	individual value of the angle θ at which the bolt force has first reached the value of $F_{p,C}$	°
θ_{1i}	individual value of the angle θ at which the bolt force has reached its maximum value $F_{b,i,max}$	°
θ_{2i}	individual value of the angle θ at which the test is stopped	°

[a] see ISO 898-1

Table H.1 *(continued)*

Symbol	Definition	Units
$\Delta\theta_{1,i}$	the individual angle difference ($\theta_{1,i}$ - $\theta_{p,i}$)	°
$\Delta\theta_{2,i}$	the individual angle difference ($\theta_{2,i}$ - $\theta_{p,i}$)	°
$\Delta\theta_{2,min}$	the minimum required value of the angle difference $\Delta\theta_{2,i}$ as specified in the relevant product standard	°
[a] see ISO 898-1		

H.3 Principle of the test

The test has the possibility to measure the following parameters during tightening:

— the bolt force;

— the torque, if required;

— the relative rotation between the nut and the bolt, if required.

H.4 Test apparatus

The bolt force measuring device may be in accordance with EN 14399-2, or a mechanical or hydraulic device such as a load cell, provided the accuracy of the bolt force-measuring device meets the requirements given in H.8. The bolt force measuring device shall be calibrated at least once per year (or more frequently if recommended by the equipment manufacturer) by a recognized testing authority.

Torque wrenches to be used for the test shall be one of those to be used on site. They shall offer suitable operating range. Hand or power wrenches may be used, with exception of impact wrenches. The accuracy requirements for the wrenches is ±4 % for the torque method or ±10 % for the combined method as appropriate. The torque wrench shall be calibrated at least once per year (or more frequently if recommended by the manufacturer).

H.5 Test assemblies

Separate tests shall be carried out on representative samples from each lot of bolting assemblies concerned. Test assemblies shall be chosen so that all relevant aspects of their conditions are similar.

NOTE The site conditions of bolting assemblies, in particular the performance of the lubrication, can vary if they are left exposed to extreme environmental conditions on site or if they are stored for a long period of time.

Representative bolting assemblies shall consist of a number of bolts, nuts and washers of each inspection lot. The assemblies used for tests shall not be re-used for supplementary tests or in the structure.

H.6 Test set-up

The test set-up (see Figure H.1) may include shims needed to suit the measuring device.

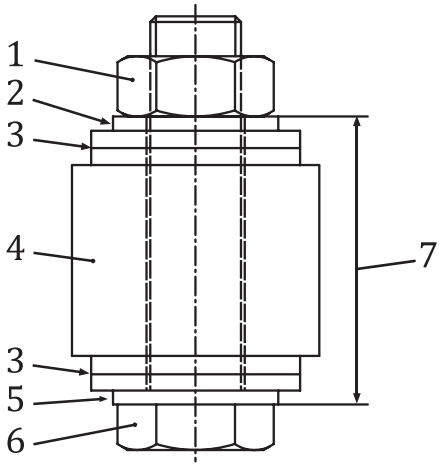
The test assemblies and shims shall be positioned such that:

— the composition of the assembly is similar to the utilization in practice;

— a chamfered washer or a chamfered shim is placed under the bolt head;

— a washer is placed under the nut when the nut will be turned during tightening;

— the clamp length including the shims and washer(s) is the minimum allowed in the relevant product standard.



Key

1 nut
2 washer under the nut when nut turned during tightening
3 shim(s)
4 bolt tension measuring device
5 chamfered washer of the assembly or chamfered shim
6 bolt head
7 clamp length Σt

Figure H.1 — Typical assembly of the tension-measuring device

H.7 Test procedure

Tests may be carried out either in a laboratory or elsewhere under suitable conditions. The method used for tightening shall be the same as that to be used on the site.

NOTE In certain cases it can be more convenient to have the product manufacturer check whether bolting assemblies still meet the declared as-delivered properties.

Sufficient measurements shall be taken of the torque, the corresponding bolt tension and, if required, the corresponding rotation of the turned part so as to permit the evaluation of the test results in accordance with H.8.

Neither the fixed part nor the washer under the turned part shall rotate during the test.

The basis of calibration is to record the torque values M_i associated with the bolt forces $F_{b,i}$ and to relate those values to target pretension in the bolt as a proportion of $F_{p,C} = 0{,}7\, f_{ub}\, A_s$.

For the torque method, the test shall be terminated when any one of the following conditions is satisfied:

— the bolt force exceeds 1,1 $F_{p,C}$;

— the angle of nut rotation exceeds ($\theta_{pi} + \Delta\theta_1$) and/or ($\theta_{p,i} + \Delta\theta_{2,min}$), if required;

— bolt failure by fracture occurs.

H.8 Evaluation of test results

The criteria for allowable maximum torque values for the combined method are given in Table H.2 where the measured torque values Mi are determined by preloading in one set of bolt assemblies to the exact value of 0,75 $F_{p,C}$.

Table H.2 — Maximum values for e_M for the combined method

Number of tests	3	4	5	6
$e_M = (M_{max} - M_{min})/M_m$	0,25	0,30	0,35	0,40

The acceptance criteria for the torque method shall be based on eight measured torque values $M_{1\text{-}8}$ determined by preloading in one set of eight bolting assemblies to the exact value of 1,10 $F_{p,C}$.

The resulting torque moment $M_{r,test}$ for preloading based on all eight of these tests shall be taken as

$$M_{r,test} = (M_{max.} + M_{min.})/2 \quad \text{(H.1)}$$

with the requirement that

$$(M_{max.} - M_{min.}) \leq 0{,}20\ M_{r,test} \quad \text{(H.2)}$$

If required to be checked, the acceptance criteria for the rotations $\Delta\theta_1$ and $\Delta\theta_2$ shall be those in the relevant part of EN 14399 for the bolting assemblies in the assembly lot.

NOTE 1 The rotations $\Delta\theta_1$ and $\Delta\theta_2$ are shown in Figure 2 of EN 14399-2:2015.

If the rotations are checked, then the maximum tension in the bolt shall be measured (i.e. that force corresponding to the rotation $\Delta\theta_1$). The requirement is that the maximum tension shall be equal to or greater than 0,9 f_{ub} A_s with f_{ub} and A_s based on nominal values.

The acceptance criteria for the spline-drive twist-off bolt method (HRC method) shall be based on the pretension from eight bolts after the fracture of the spline-ends.

The following requirements apply:

— individual value of $F_b \geq F_{p.C}$;

— mean value $F_m \geq 1{,}1\ F_{p.C}$;

— coefficient of variation of $F_{b,i}$ $V_F \leq 0{,}06$.

The acceptance criteria for the direct tension indicator (DTI) method shall be based on measuring the pretension on eight bolts when the deformations of the indicator protrusions have just reached the values given in EN 14399-9.

The following requirement applies for all eight sample values of $F_{b.i}$:

$$F_{p.C} \leq F_{b.i} \leq 1{,}2\ F_{p,C} \quad \text{(H.3)}$$

NOTE 2 Values for $F_{p,C}$ are given in Table E.1.

H.9 Test report

The following minimum information shall be included in the test report:

— date of testing;

— identification number of the bolting assembly lot or the extended bolting assembly lot;

— number of assemblies tested;

— designation of the bolting assemblies;

— marking of bolts, nuts and washers;

— coating or surface finish and lubrication condition; if relevant, description of alterations to the surfaces due to site exposure;

— test clamp length;

— details of the test set-up and devices used to measure tension and torque;

— remarks concerning the execution of tests (including special testing conditions and procedures such as turning the head of the bolt);

— tests results in accordance with this annex;

— specifications for the pretensioning of the bolting assemblies related to the inspection lot tested;

— calibration certificates for torque wrenches and calibrated force measuring devices.

The test report shall be signed and dated.

Annex I
(normative)

Pretensioning bolting assemblies — Torque method

I.1 General

This annex provides pretensioning procedures based on the torque method that may be used for pretensioned and slip-resistant joints. See 7.4.7.

— I.3, Torque method 1 is based on EN 1090-2:2018.

— I.4, Torque method 2 is based on AISC 348-20.

— I.5, Torque method 3 is based on DASt-Richtlinie 024:2018.

NOTE The contents of I.3, I.4 and I.5 do not establish any technical equivalence between the standards and documents listed.

I.2 Torque method bolting procedure

The bolting procedure shall specify:

a) torque values to be used;

b) measures necessary to control the variability in the relationship between the torque necessary to tighten the assembly and the resulting clamping force achieved.

The structural bolting assemblies shall be pretensioned using a torque wrench offering a suitable operating range. Hand, power-operated, or impact wrenches may be used for the first step of tightening for each bolt. Hand or power-operated wrenches may be used for the second step. For torque method 2, adjustable impact wrenches set to provide the required torque, then stall, may be used.

I.3 Torque method 1

The tightening torque shall be applied continuously and smoothly. Pretensioning by the torque method comprises at least the two following steps:

a) a first tightening step: the wrench shall be set to a torque value of about 0,75 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ or $M_{r,test}$. This first step shall be completed for all bolts in one connection prior to commencement of the second step;

b) a second tightening step: the wrench shall be set to a torque value of 1,10 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ or $M_{r,test}$.

NOTE 1 Torque method 1 is based on EN 1090-2:2018.

NOTE 2 The use of the 1,10 coefficient with $M_{r,2}$ is equivalent to (1 + 1,65 V_k) with V_k=0,06 for k-class K2.

The torque reference values $M_{r,i}$ to be used for a nominal minimum pretension F_p are determined for each type of bolt and nut combination used by one of the following options:

a) values based on k-class declared by the fastener manufacturer in accordance with the relevant parts of the EN 14399 series:

$M_{r,2} = k_m d F_p$ with k_m for k-class K2;

b) values determined according to Annex H:

$M_{r,test} = M_m$

with M_m determined according to the procedure relevant to the tightening method to be used.

I.4 Torque method 2

The pre-installation verification procedures specified in 7.4.6 shall be performed daily for the setting of the installation wrench for each bolt diameter, length, grade and lot. *k*-factors or torque values determined from tables or from equations that claim to relate torque to pretension without verification shall not be used.

NOTE Torque method 2 is based on AISC 348-20.

The installation torque determined in the pre-installation verification of the bolting assembly shall be applied to all nuts in the joint. The bolt head shall be prevented from rotating during this operation.

Application of the installation torque shall produce a relative rotation between the bolt and nut that is equal to than the rotation specified in Table M.1 or Table M.2, as applicable.

I.5 Torque method 3

Pretensioning for bolting assemblies according to EN 14399-4 with *k*-class K1 to a pretension level of

$F_{p,C}^* = 0{,}7\, f_{yb} A_s$

where

f_{yb} is the nominal yield strength of the bolt material;

A_s is the stress area of the bolt.

NOTE Torque method 3 is based on DASt-Richtlinie 024:2018.

Tightening by this torque method comprises at least the following steps:

a) tightening of all bolting assemblies of a joint to a snug tight condition;

b) tightening of all bolting assemblies of a joint to a pre-torque value of about 0,75 $M_{A,}$ not to exceed M_{Pre};

c) tightening of all bolting assemblies of a joint to a torque value of M_A.

Table I.1 — Pretensioning level $F_{p,C}^*$ and tightening torque values M_A for torque method 3

Bolt diameter	**M12**	**M16**	**M20**	**M22**	**M24**	**M27**	**M30**	**M36**
Pretension $F_{p,C}^*$ in kN	50	100	160	190	220	290	350	510
Tightening torque M_A in Nm	100	250	450	650	800	1 250	1 650	2 800
max. pre torque M_{Pre} in Nm	75	190	340	490	600	940	1 240	2 100

Annex J
(normative)

Pretensioning bolting assemblies — Combined method

J.1 General

Annex J provides pretensioning procedures based on the combined method that may be used for pretensioned and slip-resistant joints. See 7.4.8.

— J.2, Combined method 1 is based on EN 1090-2:2018 using EN 14399-3:2015 and EN 14399-4:2015 bolting assemblies;

— J.3, Combined method 2 is based on JASS 6:2018;

— J.4, Combined method 3 is based on AISC 348-20 using ASTM F3148 bolting assemblies and ASTM F3125 grade A325 and A490 bolts.

NOTE The contents of J.2, J.3, and J.4 do not establish any technical equivalence between the standards and documents listed.

J.2 Combined method 1

Pretensioning by the combined method for EN 14399-3 and EN 14399-4 bolting assemblies comprises two steps:

a) Using a torque wrench offering a suitable operating range, the wrench shall be set to a torque value of about 0,75 $M_{r,i}$ with $M_{r,i} = M_{r,2}$ of $M_{r,1}$ or $M_{r,test}$. This first step shall be completed for all bolts in one connection prior to commencement of the second step.

b) A specified part turn is applied to the turned part of the assembly. The position of the nut relative to the bolt threads shall be marked after the first step, using a marking crayon or marking paint, so that the final rotation of the nut relative to the thread in this second step can be easily determined.

   This step shall be in accordance with the values given in Table J.1 unless specified in the execution specification.

NOTE Combined method 1 is based on EN 1090-2:2018 using EN 14399-3:2015 and EN 14399-4:2015 bolting assemblies.

Table J.1 — Combined method 1, additional rotation (8.8 and 10.9 bolts)

Total nominal thickness t of parts to be connected (including all packs and washers) d = bolt diameter in mm	Further rotation to be applied, during the second step of tightening [a,b,c]	
	Degrees	Turn
$t < 2\,d$	60	1/6
$2\,d \le t < 6\,d$	90	1/4
$6\,d \le t \le 10\,d$	120	1/3

[a] If the rotation angle is more than 15° below the specified value, this angle shall be corrected.

[b] If the rotation angle is more than 30° over the specified angle, or the bolt or the nut has failed, the bolt assembly shall be replaced by a new one.

[c] Where the surface under the bolt head or nut (allowing for taper washers, if used) is not perpendicular to the bolt axis, the required angle of rotation should be determined by testing

The torque reference values $M_{r,i}$ to be used for a nominal minimum pretension F_p are determined for each type of bolt and nut combination used by one of the following options:

a) values based on k-class declared by the fastener manufacturer in accordance with the relevant parts of the EN 14399 series:

   1) $M_{r,2} = k_m\, d\, F_p$ with km for k-class K2;

   2) $M_{r,1} = 0{,}125\, d\, F_{p,}$ for k-class K1.

b) values determined according to Annex H:

   $M_{r,test} = M_m$

with M_m determined according to the procedure relevant to the tightening method to be used.

J.3 Combined method 2

Pretensioning by the combined method for JIS B 1186 bolting assemblies comprises three steps:

a) The torque wrench used for tightening high strength hexagon bolts shall be calibrated, generally daily, to an accuracy of ±3 %. Daily calibration at one joint shall be conducted to verify tightening accuracy prior to tightening additional joints. The complete installation process, from inserting bolts to full tightening, shall typically be finished within one day.

b) The preliminary tightening of every joint and every group of bolts shall be done in accordance with 7.2.5, immediately after the insertion of bolts. Tightening shall be done to the torque values shown in Table J.2 using a preset-type torque wrench or an electric impact wrench. After preliminary tightening, a mark running across the bolt, nut, washer and member shall be made on each bolt.

c) Full tightening shall be done by rotating the nut as shown in Table J.2 after the completion of preliminary tightening and marking. When the bolt length exceeds five times the nominal bolt size, the amount of nut rotation shall be specified in the execution specification according to the manufacturer's recommendations.

NOTE Combined method 2 is based on JASS 6:2018.

Table J.2 — Combined method 2, initial torque and additional rotation (8.8 and 10.9 bolts)

Nominal bolt diameter	Approximate torque value for preliminary tightening Nm	
M12 M16 M20 M22 M24 M27 M30	50 100 150 150 200 300 400	
L **= Nominal bolt length** ***d*** **= bolt diameter**	**Further rotation to be applied, during the second step of tightening** [a,b]	
	Degrees	**Turn**
M12, $L \leq 5d$	60	1/6
M16 – M36, $L \leq 5d$	120	1/3
$L > 5d$	Specified in the execution specification	Specified in the execution specification

[a] If the rotation angle is more than 30° under the specified value of 120° rotation (less than 90°), or if the rotation angle is more than 15° under the specified value of 60° rotation (less than 45°), the rotation shall be corrected.

[b] If the rotation angle is more than 30° above the specified angle, or the bolt or the nut has failed, the bolt assembly shall be replaced by a new one.

J.4 Combined method 3

Pretensioning by the combined method for bolting assemblies comprises three steps:

NOTE Combined method 3 is based on AISC 348-20 using ASTM F3148 bolting assemblies, ASTM F3125 grade A325 bolts, or ASTM F3125 grade A490 bolts.

a) The bolting assembly shall be installed in the bolt tension measurement device using the tools, bolting components, assembly configuration, and installation methods to be used in the work. The initial torque shall be applied to the nut. If the initial torque has not been provided by the manufacturer or supplier, then the torque in Table J.3 or the torque established by pre-installation verification testing shall be used. Tools used shall demonstrate or have certified output that does not vary by more than ±10 % during use.

Table J.3 — Combined method 3, initial torque to be applied, if not provided by the manufacturer or supplier

Nominal bolt diameter, d_b, in.	Torque range for initial torque, lb-ft (Nm) [a]							
	ASTM F3125, Grade A325				ASTM F3125, Grade A490 ASTM F3148 [b]			
	Min		Max		Min		Max	
	lb-ft	Nm	lb-ft	Nm	lb-ft	Nm	lb-ft	Nm
1/2	45	60	50	70	60	80	75	100
5/8	100	135	120	165	120	165	145	195
3/4	170	230	205	280	210	285	250	340
7/8	260	355	310	420	335	455	400	540
1	405	550	480	650	510	690	605	820

[a] This table shall not be used in lieu of manufacturer-provided torque values and shall only be used when torque has not been provided for a bolting assembly by the bolt manufacturer or supplier.

[b] ASTM F3148 Group 144 bolting assemblies are available only up to 1-1/4-in. diameter.

Table J.3 *(continued)*

Nominal bolt diameter, d_b, in.	Torque range for initial torque, lb-ft (Nm) [a]							
	ASTM F3125, Grade A325				ASTM F3125, Grade A490 ASTM F3148 [b]			
	Min		Max		Min		Max	
	lb-ft	Nm	lb-ft	Nm	lb-ft	Nm	lb-ft	Nm
1-1/8	570	775	680	920	710	965	845	1 145
1-1/4	810	1 100	965	1 310	1 010	1 370	1 200	1 625
1-3/8	1 060	1 435	1 260	1 710	1 325	1 795	1 575	2 135
1-1/2	1 390	1 885	1 655	2 245	1 735	2 350	2 065	2 800

[a] This table shall not be used in lieu of manufacturer-provided torque values and shall only be used when torque has not been provided for a bolting assembly by the bolt manufacturer or supplier.

[b] ASTM F3148 Group 144 bolting assemblies are available only up to 1-1/4-in. diameter.

b) If the actual tension developed in the bolting assembly during the first step is less than the initial tension specified in Table J.4, the cause(s) shall be determined and resolved before the bolting assemblies are used in the work. Cleaning, lubrication, and retesting of these bolting assemblies is not permitted, except as allowed in 5.2.15, provided that all assemblies are treated in the same manner.

Table J.4 — Combined method 3, minimum initial tension for pre-installation verification

Nominal bolt diameter, d_b, in.	Minimum Initial tension for pre-installation verification, kips			
	ASTM F3125, Grade A325		ASTM F3125, Grade A490 ASTM F3148 [a]	
	kips	kN	kips	kN
1/2	5	22	7	31
5/8	9	40	11	49
3/4	13	58	16	71
7/8	17	76	22	98
1	23	102	29	129
1-1/8	29	129	36	160
1-1/4	37	165	46	205
1-3/8	44	196	55	245
1-1/2	53	236	66	294

[a] ASTM F3148 Group 144 bolting assemblies are available only up to 1-1/4-in. diameter.

c) If location marks are required by the execution specification, the bolting assembly shall be marked.

d) The rotation specified in Table J.5 shall be applied to each bolting assembly.

Table J.5 — Combined method 3, Nut rotation after application of initial torque [a,b]

Bolt length [c]	Rotation
Not more than 4 d_b	90° (1/4 turn)
More than 4 d_b but not more than 8 d_b	120° (1/3 turn)

[a] Nut rotation is relative to bolt regardless of the element (nut or bolt) being turned. For all required nut rotations, the tolerance is plus 45° (+1/8 turn) and minus 0°.

[b] Applicable only to joints in which all material within the grip is steel.

[c] When the bolt length exceeds 8 d_b, the required nut rotation shall be determined by actual testing in a suitable bolt tension measurement device.

Annex K
(normative)

Pretensioning bolting assemblies — Spline-drive twist-off method

The shear wrench used for installation operates as follows:

— during the tightening operation of a structural bolting assembly, the socket in rotation is the one that finds the least resistance to it;

— from the outset and right up to the last tightening step, the outer socket on the nut rotates clockwise while the inner socket holds the spline end without rotating, the result being that the structural bolting assembly is progressively tightened by the increasing torque applied to the nut;

— at the last tightening step, i.e. when the torsional resistance plateau of the break-neck section is attained, the inner socket rotates anticlockwise while the outer socket on nut provides the reaction without rotating;

— the structural bolting assembly installation is complete when the spline end shears off at the break-neck section.

The specified pretension requirement is provided by the twist-off structural bolting assembly itself by means of the geometrical and torsion mechanical characteristics, together with the lubrication conditions. The installation wrench does not need calibration.

In order to ensure that the pretension in completed structural bolt assemblies in connections meet the specified minimum pretension requirement, the bolt installation process comprises two tightening steps.

All twist-off structural bolting assemblies shall be placed in the connection. The first tightening step of bringing the joint to the snug-tight condition may be achieved using the shear wrench or other style wrench to bring the connected plies into firm contact, without severing the splined end. If a splined end is severed during this operation, the bolting assembly shall be removed and replaced. This first step shall be completed for all structural bolts in the connection prior to commencement of the second step.

NOTE 1 Guidance of the equipment manufacturer can give additional information on how to identify if snug tightening has occurred, e.g. sound of shear wrench changing, or if other methods of snug tightening are suitable.

If required by the execution specification, after the first tightening step, a mark running across the structural bolt, nut, washer and member shall be made on each twist-off bolt assembly.

The second tightening step is achieved when the spline end of the structural bolt shears off at the break-neck.

If required by the execution specification, the k-class shall be limited to *k*-class K0, K1and K2 with HRD nuts, or k-class K2 with HR nuts.

NOTE 2 The k-class limitations are applicable only for EN-14399-10 HRC assemblies.

If the assembly conditions are such that it is not possible to use the shear wrench on the twist-off structural bolting assembly, e.g. for lack of space, tightening shall be carried out using an alternative pretensioning procedure permitted by the execution specification (e.g. torque method, combined method, direct tension indicator method, turn-of-nut method).

Annex L
(normative)

Pretensioning bolting assemblies — Direct tension indicator method

Direct tension indicators shall indicate, by compression of the protrusions, that at least the required minimum pretension has been achieved in the structural bolting assembly.

NOTE 1 This annex does not apply to indicators that rely on torsion.

NOTE 2 This annex does not apply to direct measurement of structural bolt pretension by use of hydraulic instruments or ultrasonic instruments.

The direct tension indicators and their associated washers shall be assembled in accordance with the product standard and the manufacturer's written instructions, if applicable. See 7.2.8.2.

The job inspection gap shall be provided by the manufacturer, or established by the contractor during pre-installation verification testing, as a gap less than the measured DTI test gap at 1,05 × the minimum required bolt pretension.

The first step of tightening to reach a uniform snug-tight condition of a bolting assembly shall be when initial deformation of the direct tension indicator protrusions begins. The installer shall verify that the direct tension indicator protrusions have not been compressed to a gap that is less than the job inspection gap during this operation, and if this has occurred, the direct tension indicator shall be removed and replaced. This first step shall be completed for all structural bolts in the connection prior to commencement of the second step.

The second step of tightening shall be to apply further tightening until the job inspection gap requirements are met for each direct tension indicator. The installer shall verify that the direct tension indicator protrusions have been compressed to a gap that is less than the job inspection gap. The gaps measured on the direct tension indicator may be averaged to establish the acceptability of the structural bolting assembly.

Annex M
(normative)

Pretensioning bolting assemblies — Turn-of-nut method

M.1 General

Annex M provides pretensioning procedures based on the turn-of-nut method that may be used for pretensioned and slip-resistant joints. See 7.4.11.

NOTE The contents of M.3 and M.4 do not establish any technical equivalence between the standards and documents listed.

— M.3, Turn-of-nut method 1 is based on AISC 348-20 and AS/NZ 5131:2016;

— M.4, Turn-of-nut method 2 is based on CSA S16-19.

M.2 Turn-of-nut method – General

The turn-of-nut method provides bolt pretension through elongation of the bolt when the nut is sufficiently rotated relative to the bolt, ensuring that at least the required minimum pretension has been achieved in the bolt.

The specified pretension requirement is provided by the structural bolting assembly itself by means of the geometrical and mechanical characteristics with deformation control, provided adequate lubrication conditions are present. The installation wrench does not need calibration.

In order to ensure that the pretensions in fully installed structural bolts in connections meet the specified minimum pretension requirement, the bolt installation process comprises two tightening steps.

All structural bolting assemblies shall be placed in the connection. The first tightening step to reach a uniform snug-tight condition of a bolting assembly may be achieved using a few impacts of a pneumatic impact wrench, an appropriate level of torque from electric or hydraulic tools, generally in the range of half the torque needed to achieve full pretension, or by the full effort of a person using a standard hand podger spanner or spud wrench. This first step shall be completed for all structural bolts in one connection prior to commencement of the second step.

If required by the execution specifications, after snug tightening, location marks (matchmarks) shall be established to mark the relative position of the structural bolt and the nut and to control the final nut rotation.

The second tightening step is to apply nut or head rotation in accordance with Table M.1 or Table M.2, as applicable, to all bolting assemblies in the joint. The part not turned by the wrench shall be prevented from rotating during this operation, unless the structural bolt and nut are marked to enable the amount of relative rotation to be determined. Observation of the final nut rotation may be achieved by using marked wrench sockets or by using location marks.

M.3 Turn-of-nut method 1

NOTE 1 Turn-of-nut method 1 is based on AISC 348-20 and AS/NZ 5131:2016.

NOTE 2 Table M.1 is based on the use of ASTM F3125 grades A325 and A490 and AS/NZS 1252 grades 8.8 and 10.9.

Table M.1 — Turn-of-nut method 1

L **= Nominal bolt length** ***d*** **= bolt diameter**	**Further rotation to be applied beyond snug-tight condition**					
	Both faces normal to bolt axis		**One face normal, other face sloped but not more than 1:20 from bolt axis, bevelled washer not used**		**Both faces sloped, but not more than 1:20 from bolt axis, bevelled washer not used**	
	Degrees	Turn	Degrees	Turn	Degrees	Turn
$L \leq 4\,d$	120	1/3	180	1/2	240	2/3
$4\,d \leq L \leq 8\,d$	180	1/2	240	2/3	300	5/6
$8\,d < L \leq 12\,d$ [a]	240	2/3	300	5/6	360	1

[a] For $L > 12\,d$, rotation to be determined by testing.

NOTE 1 AISC 348 — Rotation tolerance +60°, -0°.

NOTE 2 AS/NZS 5131 — Rotation tolerance +30°, -0° for rotations of ½ turn or less, +45°, -0° for rotations of 2/3 turn or more.

M.4 Turn-of-nut method 2

NOTE 1 Turn-of-nut method 2 is based on CSA S16-19.

NOTE 2 Table M.2 is based on the use of ASTM F3125/F3125M grades A325, A325M, A490 and A490M.

Table M.2 — Turn-of-nut method 2

L **= Nominal bolt length** ***d*** **= bolt diameter**	**Further rotation to be applied beyond snug-tight condition**					
	Both faces normal to bolt axis		**One face normal, other face sloped but not more than 1:20 from bolt axis, bevelled washer not used** [a]		**Both faces sloped, but not more than 1:20 from bolt axis, bevelled washer not used** [a]	
	Degrees	Turn	Degrees	Turn	Degrees	Turn
$L \leq 4d$	120	1/3	120	1/3	270	3/4
$4d \leq L \leq 8d$, not to exceed 200 mm	180	1/2	180	1/2		
$8d < L \leq 12$, or bolt length exceeding 200 mm	240	2/3	240	2/3		

[a] Bevelled washers required under sloping surfaces when Grade A490 or A490M bolts are used.

NOTE Tolerance ±30° for all rotations.

Annex N
(informative)

Bolt tightening qualification procedure (BTQP)

N.1 General

This annex only applies if no rules and parameters for tightening exist, e.g. for pretensioning of stainless-steel bolting assemblies, or when bolts are pretensioned by turning the head.

This annex presents a BTQP which provides design and execution rules for pretensioning of stainless-steel and carbon steel bolting assemblies with bolting assemblies consisting of one bolt, one nut, and washers as required for the installation method. One washer should be installed between the clamping package and the bolt head and the other washer should be installed between the clamping package and the nut.

The BTQP allows the determination of the tightening parameters for only one configuration. In this procedure, one configuration is:

— one single bolting assembly lot (i.e. bolts from one manufacturing lot, nuts from one manufacturing lot, washers from one manufacturing lot), see ISO 17607-1;

— one lubrication;

— one tightening method, with a defined pretension level.

The BTQP should be performed for each new configuration.

The specified pretension shall not exceed the nominal pretension level.

The BTQP includes:

— the definition of appropriate lubrication to ensure a sufficiently long plastic plateau of the bolt force–rotation curve (the ability to demonstrate the required functional characteristics of the bolting assembly is highly dependent on the type of lubrication used);

— the evaluation of tightening parameters;

— a suitability test to confirm that the required pretension can be reliably obtained by a specific tightening method with a sufficient margin of safety against overtightening.

This annex applies only to static design. Fatigue considerations may govern the design and should also be assessed.

A schematic overview of the BTQP is given in Figure N.1. The detailed parameters and requirements are given in N.2 through N.5.

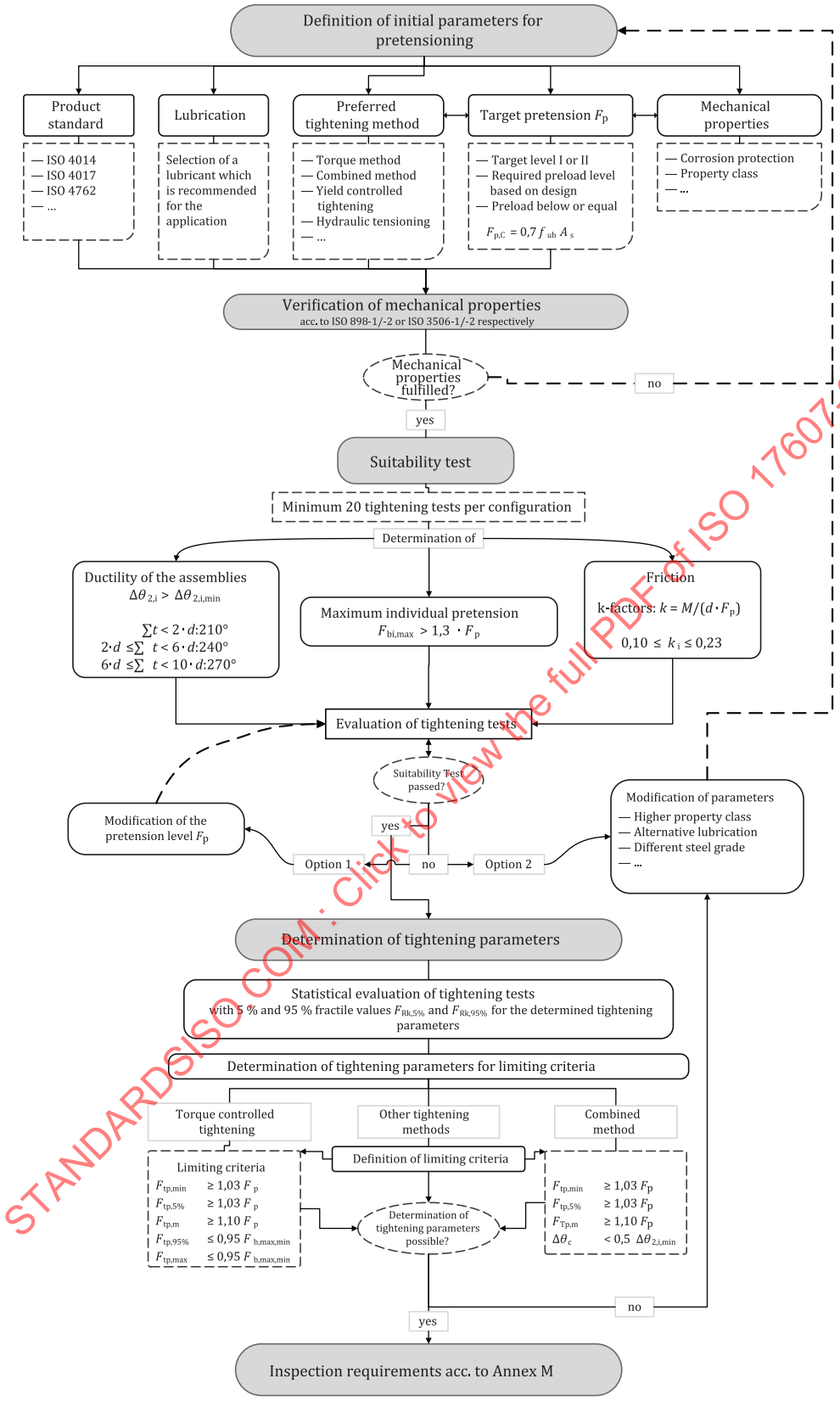


Figure N.1 — Schematic overview of the bolt tightening qualification procedure (BTQP)

N.2 Mechanical properties of bolting components

The bolting assemblies should fulfil the requirements according to ISO 3506-1 and ISO 3506-2 for stainless-steel bolting assemblies, and according to ISO 898-1 and ISO 898-2 for carbon steel bolting assemblies.

N.3 Suitability test

N.3.1 General

A minimum of 20 tightening tests shall be performed for each configuration.

Unless otherwise specified, tightening shall be carried out by rotation of the nut. If tightening is carried out by rotation of the bolt head, the test set-up and the procedure described in this clause shall be modified accordingly.

The principle of the test is to tighten the assembly and to measure in a continuous manner, during tightening, the following parameters:

— the bolt force;

— the relative rotation between the nut and the bolt;

— the torque.

N.3.2 Test apparatus

The test apparatus shall be able to determine the parameters according to N.3.1 in a continuous manner during the tightening process.

The test apparatus shall be made of steel.

The block on which the assembly is mounted shall be sufficiently rigid.

NOTE Hydraulic measuring devices do not normally meet this requirement.

It is recommended that the stiffness of the test set-up be as high as practicable.

The length of the bolt between the head and the nut shall be adjusted by the use of shims as specified in Table N.1.

The number of shims shall not exceed four.

The bolt force shall be measured in a continuous manner by a calibrated device (e. g. dynamometer) with uncertainty of ±2 % of the actual value and a repeatability error of ±1 %.

The rotation shall be measured in a continuous manner to an uncertainty of ±1°.

The torque shall be measured in a continuous manner by a calibrated torque measuring device with an uncertainty of the value and a repeatability error of ±1 %.

Table N.1 — Characteristics of shims

Nominal bolt diameter *d* mm	Hole diameter mm	Outside diameter mm	Thickness mm	Hardness for the outside shim HRC	Parallelism
$d \leq$ M14	$d + 1$	Not less than the outside assembly washer diameter and sufficient to distribute load adequately to the device	≥ 2	≥ 45 through hardened	≤ 1 %
M14 < $d \leq$ M24	$d + 2$				
$d >$ M24	$d + 3$				

N.3.3 Test assemblies

The test shall be carried out on assemblies that include at least a washer under the rotated element (nut or bolt head).

Test assemblies shall be taken from a single assembly lot.

Each component of a test assembly shall be used once only, unless otherwise specified.

Lubrication conditions shall be defined. The tests shall be carried out under the lubrication conditions which will be applied in the later use.

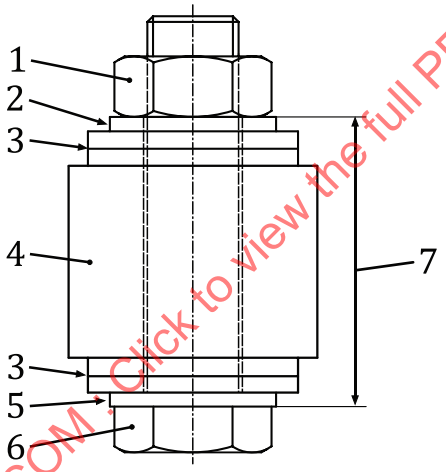
N.3.4 Test set-up

The test set-up (see Figure N.2) may include shims (see Table N.1) needed to suit the measuring device.

The test assemblies and shims shall be positioned such that:

— a washer of the assembly is placed under the rotated element (nut/bolt head);

— the clamp length including shims and washer(s) is the minimum allowed in the relevant product standard.



Key

1 nut: turned during tightening
2 washer of the assembly: prevented from rotating
3 shim(s)
4 calibrated bolt force measuring device
5 washer of the assembly or shim
6 bolt head: prevented from rotating
7 clamp length Σt

Figure N.2 — Test set-up

N.3.5 Test procedure

The test shall be carried out at an ambient temperature range of 10 °C to 35 °C.

Unless otherwise specified, the tightening shall be carried out by rotation of the nut. In principle, tightening by rotation of the bolt head is possible. Within this test procedure, the rotation of the nut is described. If the bolt head is to be rotated for tightening, the given test set-up and the procedure shall be modified accordingly.

The tightening shall be carried out by rotation in a continuous manner and measurements shall be recorded throughout the test.

The speed of rotation of the test shall be between 1 and 10 min^{-1} (revolutions per minute).

Neither the bolt nor the washer under the nut shall rotate during the test. If either of them rotates during tightening, the phenomena shall be noted and a new test shall be carried out to replace the test in question.

The test shall be stopped when any one of the following conditions is first satisfied:

— the angle of nut rotation exceeds ($\theta_{pi} + \Delta\theta_{2,i,min}$);

— the bolt force drops to F_p;

— bolt failure by fracture occurs.

For each of the test assemblies the following curves shall be determined:

— the bolt force-rotation relationship;

— the bolt force-torque relationship;

— the bolt force-elongation relationship, if required.

The data of these relationships shall be such as to permit accurate interpretation of the results and be consistent with the accuracy of the test apparatus (see examples of curves in Figures N.3 and N.4).

N.3.6 Evaluation of the test results

The following shall be obtained from each curve in accordance with Figure N.3:

— the angle θ_{pi} at which the bolt force first reaches the value of F_p; θ_{pi} is noted;

— the angle θ_{1i} at which the bolt force reaches its maximum value $F_{b,max}$, $F_{b,max}$ is also noted;

— the angle θ_{2i} at which the test is stopped and at which the value of the bolt force F_b (θ_{2i}) is also noted.

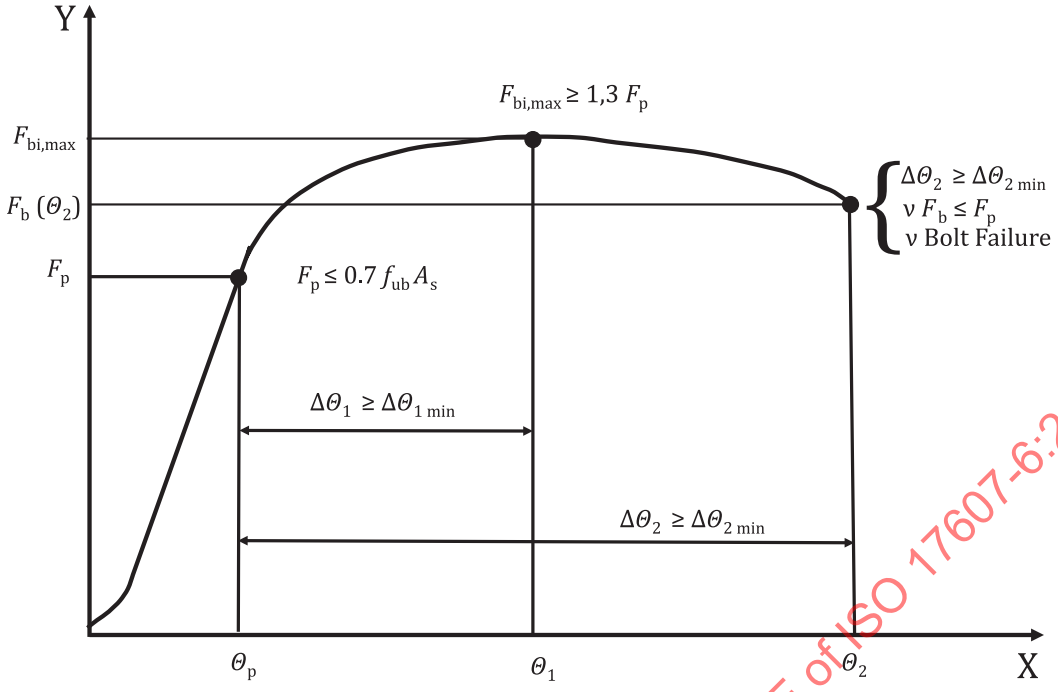
The minimum value of all $F_{b,max}$ values, $F_{b,max,min}$, is also noted.

Although the purpose of measuring the angle θ_{2i} is to obtain an indication of the nut rotation at which the bolt force drops back to the value F_b, in practice the test may be stopped when the angle difference $\Delta\theta_{2i}$ reaches the specified required minimum value $\Delta\theta_{2\,min}$ according to the BTQP.

From the above angle measurements, the following values are determined:

— the angle difference $\Delta\theta_{1i}$, which is defined as ($\theta_{1i} - \theta_{pi}$) and corresponds to the point at which the maximum bolt force $F_{b,max}$ has been reached;

— the angle difference $\Delta\theta_{2i}$, which is defined as ($\theta_{2i} - \theta_{pi}$) and corresponds to the point at which the test has been stopped.

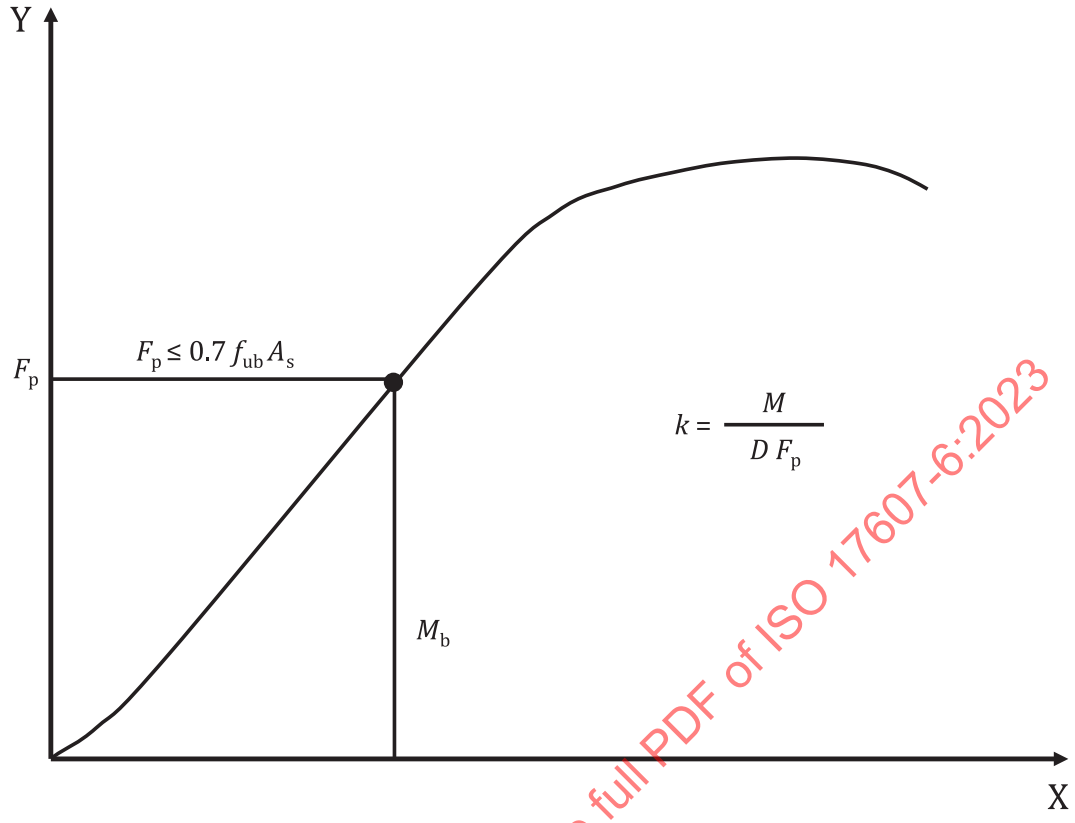


Key

X angle of rotation θ in °

Y bolt force F_b in kN

Figure N.3 — Bolt force-rotation curve



Key

X tightening torque M in Nm

Y bolt force F_b in kN

Figure N.4 — Bolt force-torque curve (F/M curve)

N.3.7 Requirements for suitability

N.3.7.1 General

The functional characteristics of the bolt/nut/washer(s) assembly specified in this clause shall be achieved.

N.3.7.2 Maximum individual value of the bolt force during the tightening test ($F_{b,max}$)

The maximum individual value of the bolt force during the tightening test should satisfy the following:

$$F_{b,max} \geq 1,3\, F_p \qquad \text{(N.1)}$$

If the conditions in Formula (N.1) are not fulfilled, the modification of the pretension level F_p or the modification of other parameter, such as the lubrication can help satisfy the formula, see Figure N.1.

N.3.7.3 Angle of additional nut rotation

The angle by which the nut should be turned starting from a pretension of F_p until the bolt force has dropped back to F_p specified in Table N.2.

Table N.2 — Values for angles of additional nut rotation $\Delta\theta_{2i}$

Clamp length Σt [a]	$\Delta\theta_{2i,min}$
$\Sigma t < 2d$	210°
$2d \leq \Sigma t < 6d$	240°
$6d \leq \Sigma t < 10d$	270°
[a] Σt is the total thickness of the clamped parts including washer(s).	

N.3.7.4 Individual values of the k-factor

Individual k_i-values are required and shall be in the range of $0{,}10 \leq k_i \leq 0{,}23$, with $k_i = M/(d \times F_p)$.

The BTQP evaluates individual k-factors to limit torsion in the bolting assembly. Tightening parameters shall be evaluated within the BTQP.

N.3.8 Test report

The following minimum information shall be included in the test documentation:

a) identification of the laboratory;

b) identification of the organization ordering the test;

c) date of reception of the assemblies;

d) date of testing;

e) identification number of the assembly lot or the extended assembly lot (provided by the client);

f) number of assemblies tested;

g) designation of the fasteners;

h) marking of bolts, nuts and washers;

i) coating or surface finish;

j) lubrication;

k) test clamp length;

l) details of the test set-up including rigidity;

m) tightening conditions (speed of tightening, number of shims);

n) remarks concerning the execution of tests (including, if any, those on special testing conditions and procedures);

o) tests results according to this document;

p) evaluation of the functional characteristics of the assembly lot in relation to the requirements of the BTQP;

q) conclusions.

N.4 Determination of tightening parameters

N.4.1 General

Pretensioned bolted connections are categorised as:

— connections in which the pretension is used in the design process, e.g. slip-resistant connections or pretensioned tensile connections (target level I);

— connections which are pretensioned only to enhance the serviceability, e. g. to limit the deformation and slip in the connections (target level II).

Based on the chosen tightening method, tightening parameters (e.g. reference torque, additional angle of rotation if needed) shall be determined to fulfil the requirements given in N.4.2.

N.4.2 Criteria for the determination of the tightening parameters

The individual values of the bolt force F_{tpi} related to the considered tightening parameter are determined for each suitability test. The tightening parameters are determined by considering the following values:

$F_{tp,min}$ the minimum value of all F_{tpi} values.

$F_{tp,max}$ the maximum value of all F_{tpi} values.

$F_{tp,m}$ the mean value of all F_{tpi} values.

$F_{tp,5\,\%}$ the 5 % fractile of all F_{tpi} values.

$F_{tp,95\,\%}$ the 95 % fractile of all F_{tpi} values.

The tightening parameters (bolt pretension achieved in tightening tests) are determined by considering the 5 % and 95 % fractile values, assuming a normal distribution of the test results with unknown coefficients of variation.

$$F_{tp,5\,\%} = F_{tp,m} \times (1 - k_n \times V_F) \tag{N.2}$$

$$F_{tp,95\,\%} = F_{tp,m} \times (1 + k_n \times V_F) \tag{N.3}$$

with

$$F_{tp,m} = \frac{\sum F_{tpi}}{n} \tag{N.4}$$

$$V_F = \frac{s_F}{F_{b,m}} \tag{N.5}$$

$$s_F = \sqrt{\frac{1}{n-1} \times \sum \left(F_{tpi} - F_{tp,m}\right)^2} \tag{N.6}$$

where:

k_n is the quantile factor according to Table N.3;

n is the amount of test results within a test series;

s_F is the calculated standard deviation of the F_{bi} values;

V_F is the calculated coefficient of variation of the F_{bi} values.

Table N.3 — k_n -values for statistical evaluation, assuming a normal distribution of the test results with unknown coefficients of variation

n	20	25	30	≥ 40
k_n	1,76	1,74	1,73	1,64

The limiting criteria No. 1 to 3 given in Table N.4 shall be fulfilled.

NOTE Once the evaluation of tightening parameters in accordance with the limiting criteria given in Table N.4 has been undertaken, the tightening parameters can be relaxed for applications only required to meet target level II.

The limiting criteria 4T and 5T given in Table N.4 shall be fulfilled if a torque controlled tightening method is used.

The limiting criterion 4C given in Table N.4 shall be fulfilled if a combined tightening method is used.

Table N.4 — Criteria for the determination of tightening parameters

No.	Limiting criteria to be fulfilled, when evaluated tightening parameters are applied[a]	
Criteria to ensure the minimum value of pretension F_p is reliably applied		
1	The lowest individual pretension $F_{tp,min}$ from one test series shall exceed the required minimum pretension F_b by at least 3 %	$F_{tp,min} \geq 1{,}03\ F_p$
2	The 5 % fractile of the individual pretensions $F_{tp,5\,\%}$ from one test series shall exceed the required minimum pretension F_b by at least 3 %	$F_{tp,5\%} \geq 1{,}03\ F_p$
3	The mean value of the individual pretension $F_{tp,m}$ from one test series shall exceed the required minimum pretension F_b by at least 10 %	$F_{tp,m} \geq 1{,}1\ F_p$
Criteria to avoid overtightening of the bolting assembly components up to fracture when evaluating parameters for a torque controlled tightening method		
4T	The 95 % fractile of the individual pretension $F_{tp,95\,\%}$ of one test series shall be less than or equal to 95 % of the minimum value of all $F_{b,max}$ values within a test series	$F_{tp,95\,\%} \leq 0{,}95\ F_{b,max,min}$
5T	The highest individual pretension $F_{tp,max}$ of one test series shall be less than or equal to 95 % of the minimum value of all $F_{b,max}$ values within a test series	$F_{tp,max} \leq 0{,}95 \cdot F_{b,max,min}$
Criteria to avoid overtightening of the bolting assembly components up to fracture when evaluating parameters for a combined tightening method		
4C	The additional angle of nut rotation, beginning after the application of the tightening torque in the first step of the combined method, shall not exceed 50 % of the minimum required value of the angle difference $\Delta\theta_{2i,min}$	$\Delta\theta_c \leq 0{,}5\ \Delta\theta_{2i,min}$
[a] The limiting criteria given in this table shall ensure, that with evaluated tightening parameters, the desired preload is applied in the bolting assembly and overtightening is prevented		

N.5 Inspection requirements

Inspection requirements should be defined in accordance with Annex O.