
Specification for Structural Joints Using High-Strength Bolts

August 1, 2014

Supersedes the December 31, 2009 *Specification for
Structural Joints Using High-Strength Bolts*.

Prepared by RCSC Committee A.1—Specifications and
approved by the Research Council on Structural Connections.



www.boltcouncil.org

RESEARCH COUNCIL ON STRUCTURAL CONNECTIONS
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PREFACE

The purpose of the Research Council on Structural Connections (RCSC) is:

- (1) To stimulate and support such investigation as may be deemed necessary and valuable to determine the suitability, strength and behavior of various types of structural connections;
- (2) To promote the knowledge of economical and efficient practices relating to such structural connections; and,
- (3) To prepare and publish related specifications and such other documents as necessary to achieving its purpose.

The Council membership consists of qualified structural engineers from academic and research institutions, practicing design engineers, suppliers and manufacturers of fastener components, fabricators, erectors and code-writing authorities.

The first Specification approved by the Council, called the *Specification for Assembly of Structural Joints Using High Tensile Steel Bolts*, was published in January 1951. Since that time the Council has published seventeen successive editions. Each was developed through the deliberations and approval of the full Council membership and based upon past successful usage, advances in the state of knowledge and changes in engineering design practice. This edition of the Council's *Specification for Structural Joints Using High-Strength Bolts* continues the tradition of earlier editions. The major changes are:

- Appendix B provisions were incorporated directly into Section 5 of the *Specification*.
- Tolerances for the Turn-of- Nut method were adjusted.
- Glossary definitions for "pretension" were added.
- F1136 coating on F1852 and F2280 bolts was deleted from Table 2.1 in recognition that this coating has not been approved by ASTM for use on TC bolts.
- Slip critical equations in Section 5.4 were updated for consistent with the AISC Specification.
- Clarification language was provided for approval requirements for hole sizes other than standard holes.
- The snug-tightened joint definition was redefined back to the 2004 definition due to issues regarding turn-of-nut tension requirements.

In addition, typographical changes have been made throughout this Specification.

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SYMBOLS

The following symbols are used in this Specification.

A_b	Cross-sectional area based upon the nominal diameter of bolt, in. ²
D	Slip probability factor as described in Section 5.4.2
D_u	Multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension, T_m , as described in Section 5.4.1
F_n	Nominal strength (per unit area), ksi
F_u	Specified minimum tensile strength (per unit area), ksi
I	Moment of inertia of the built-up member about the axis of buckling (see the Commentary to Section 5.4), in. ⁴
L	Total length of the built-up member (see the Commentary to Section 5.4), in.
L_s	Length of a connection measured between extreme bolt hole centers parallel to the line of force (see Table 5.1), in.
L_c	Clear distance, in the direction of load, between the edge of the hole and the edge of the adjacent hole or the edge of the material, in.
N_b	Number of bolts in the joint
P_u	Required strength in compression, kips; Axial compressive force in the built-up member (see the Commentary to Section 5.4), kips
Q	First moment of area of one component about the axis of buckling of the built-up member (see the Commentary to Section 5.4), in. ³
R_n	Nominal strength, kips
T	Applied service load in tension, kips
T_m	Specified minimum bolt pretension (for pretensioned joints as specified in Table 8.1), kips
T_u	Required strength in tension (factored tensile load), kips

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V_u	Required strength in shear (factored shear load), kips
d_b	Nominal diameter of bolt, in.
t	Thickness of the connected material, in.
t'	Total thickness of fillers or shims (see Section 5.1), in.
k_s	Slip coefficient for an individual specimen determined in accordance with Appendix A
ϕ	Resistance factor
ϕR_n	Design strength, kips
μ	Mean slip coefficient

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GLOSSARY

The following terms are used in this Specification. Where used, they are italicized to alert the user that the term is defined in this Glossary.

Allowable Strength. *Nominal strength, R_n* , divided by the safety factor, Ω .

Available Strength. Design Strength or Allowable Strength, as appropriate.

ASD Load. Load due to a load combination in the applicable building code intended for allowable strength design (allowable stress design).

Coated Faying Surface. A *faying surface* that has been primed, primed and painted or protected against corrosion, except by hot-dip galvanizing.

Connection. An assembly of one or more *joints* that is used to transmit forces between two or more members.

Contractor. The party or parties responsible to provide, prepare and assemble the fastener components and connected parts described in this Specification.

Design Strength. ϕR_n , the resistance provided by an element or *connection*; the product of the *nominal strength, R_n* , and the resistance factor ϕ .

Engineer of Record. The party responsible for the design of the structure and for the approvals that are required in this Specification (see Section 1.6 and the corresponding Commentary).

Fastener Assembly. An assembly of fastener components that is supplied, tested and installed as a unit.

Faying Surface. The plane of contact between two plies of a *joint*.

Firm Contact. The condition that exists on a *faying surface* when the plies are solidly seated against each other, but not necessarily in continuous contact.

Galvanized Faying Surface. A *faying surface* that has been hot-dip galvanized.

Grip. The total thickness of the plies of a *joint* through which the bolt passes, exclusive of washers or direct-tension indicators.

Guide. The *Guide to Design Criteria for Bolted and Riveted Joints*, 2nd Edition (Kulak et al., 1987).

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High-Strength Bolt. An ASTM A325 or A490 bolt, an ASTM F1852 or F2280 twist-off-type tension-control bolt or an alternative-design fastener that meets the requirements in Section 2.8.

Inspector. The party responsible to ensure that the *contractor* has satisfied the provisions of this Specification in the work.

Joint. A bolted assembly with or without collateral materials that is used to join two structural elements.

Lot. In this Specification, the term *lot* shall be taken as that given in the ASTM Standard as follows:

Product	ASTM Standard	See Lot Definition in ASTM Section
Conventional bolts	A325	9.4
	A490	11.4
Twist-off-type tension-control bolt assemblies	F1852	13.4
	F2280	3.1.1
Nuts	A563	9.2
Washers	F436	9.2
Compressible-washer-type direct tension indicators	F959	10.2.2

LRFD Load. Load due to a load combination in the applicable building code intended for strength design (load and resistance factor design).

Manufacturer. The party or parties that produce the components of the *fastener assembly*.

Mean Slip Coefficient. μ , the ratio of the frictional shear load at the *faying surface* to the total normal force when slip occurs.

Nominal Strength. The capacity of a structure or component to resist the effects of loads, as determined by computations using the specified material strengths and dimensions and equations derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modeling effects and differences between laboratory and field conditions.

Pretension (noun). A level of tension achieved in a fastener assembly through its installation, as required for *pretensioned* and *slip-critical joints*.

Pretension (verb). The act of tightening a fastener assembly to a level required for *pretensioned* and *slip-critical joints*.

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Pretensioned Joint. A joint that transmits shear and/or tensile loads in which the bolts have been installed in accordance with Section 8.2 to provide a pretension in the installed bolt.

Protected Storage. The continuous protection of fastener components in closed containers in a protected shelter as described in the Commentary to Section 2.2.

Prying Action. Lever action that exists in *connections* in which the line of application of the applied load is eccentric to the axis of the bolt, causing deformation of the fitting and an amplification of the axial tension in the bolt.

Required Strength. The load effect acting on an element or *connection* determined by structural analysis from the factored loads using the most appropriate critical load combination.

Routine Observation. Periodic monitoring of the work in progress.

Shear/Bearing Joint. A *snug-tightened joint* or *pretensioned joint* with bolts that transmit shear loads and for which the design criteria are based upon the shear strength of the bolts and the bearing strength of the connected materials.

Slip-Critical Joint. A joint that transmits shear loads or shear loads in combination with tensile loads in which the bolts have been installed in accordance with Section 8.2 to provide a pretension in the installed bolt (clamping force on the *faying surfaces*), and with *faying surfaces* that have been prepared to provide a calculable resistance against slip.

Snug-Tightened Joint. A joint in which the bolts have been installed in accordance with Section 8.1. The snug tightened condition is the tightness that is attained with a few impacts of an impact wrench or the full effort of an ironworker using an ordinary spud wrench to bring the plies into *firm contact*.

Start of Work. Any time prior to the installation of *high-strength bolts* in structural *connections* in accordance with Section 8.

Sufficient Thread Engagement. Having the end of the bolt extending beyond or at least flush with the outer face of the nut; a condition that develops the strength of the bolt.

Supplier. The party that sells the fastener components to the party that will install them in the work.

Tension Calibrator. A calibrated tension-indicating device that is used to verify the acceptability of the pretensioning method when a *pretensioned joint* or *slip-critical joint* is specified.

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Uncoated Faying Surface. A *faying surface* that has neither been primed, painted, nor galvanized and is free of loose scale, dirt and other foreign material.

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SPECIFICATION FOR STRUCTURAL JOINTS USING HIGH-STRENGTH BOLTS

SECTION 1. GENERAL REQUIREMENTS

1.1. Scope

This Specification covers the design of bolted *joints* and the installation and inspection of the assemblies of fastener components listed in Section 1.5, the use of alternative-design fasteners as permitted in Section 2.8 and alternative washer-type indicating devices as permitted in Section 2.6.2, in structural steel *joints*. This Specification relates only to those aspects of the connected materials that bear upon the performance of the fastener components. The Symbols, Glossary and Appendices are a part of this Specification.

Commentary:

This Specification deals principally with two strength grades of *high-strength bolts*, ASTM A325 and A490, and with their design, installation and inspection in structural steel *joints*. Equivalent fasteners, however, such as ASTM F1852 (equivalent to ASTM A325) and F2280 (equivalent to ASTM A490) twist-off-type tension-control bolt assemblies, are also covered. These provisions may not be relied upon for high-strength fasteners of other chemical composition, mechanical properties, or size. These provisions do not apply when material other than steel is included in the *grip*; nor are they applicable to anchor rods.

This Specification relates only to the performance of fasteners in structural steel *joints* and those few aspects of the connected material that affect this performance. Many other aspects of *connection* design and fabrication are of equal importance and must not be overlooked. For more general information on design and issues relating to *high-strength bolting* and the connected material, refer to current steel design textbooks and the *Guide to Design Criteria for Bolted and Riveted Joints*, 2nd Edition (Kulak et al., 1987).

1.2. Loads, Load Factors and Load Combinations

The design and construction of the structure shall conform to either an applicable load and resistance factor design specification for steel structures or to an applicable allowable strength design specification for steel structures. Because factored load combinations account for the reduced probabilities of maximum loads acting concurrently, the *design strengths* given in this Specification shall not be increased.

1.3 Design for Strength Using Load and Resistance Factor Design (LRFD)

Design according to the provisions for load and resistance factor design (LRFD) satisfies the requirements of this Specification when the design strength of each

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structural component or assemblage equals or exceeds the required strength determined on the basis of the LRFD load combinations.

Design shall be performed in accordance with Equation 1.1

$$R_u \leq \phi R_n \quad (\text{Equation 1.1})$$

Where

R_u = required strength using LRFD load combinations

R_n = nominal strength

ϕ = resistance factor

ϕR_n = design strength

1.4 Design for Strength Using Allowable Strength Design (ASD)

Design according to the provisions for allowable strength design (ASD) satisfies the requirements of this Specification when the design strength of each structural component or assemblage equals or exceeds the required strength determined on the basis of the ASD load combinations.

Design shall be performed in accordance with Equation 1.2

$$R_u \leq R_n / \Omega \quad (\text{Equation 1.2})$$

Where

R_u = required strength using ASD load combinations

R_n = nominal strength

Ω = safety factor

R_n / Ω = allowable strength

Commentary:

This Specification is written in a dual format covering both load and resistance factor design (LRFD) and allowable strength design (ASD). Both approaches provide a method of proportioning structural components such that no applicable limit state is exceeded when the structure is subject to all appropriate load combinations. When a structure or structural component ceases to fulfill the intended purpose in some way, it is said to have exceeded a limit state. Strength limit states concern maximum load-carrying capability, and are related to safety. Serviceability limit states are usually related to performance under normal service conditions, and usually are not related to strength or safety. The term “resistance” includes both strength limit states and serviceability limit states.

Although loads, load factors and load combinations are not explicitly specified in this Specification, the safety and resistance factors herein are based upon the loads, load factors and load combinations specified in ASCE 7. When the design is governed by other load criteria, the safety and resistance factors specified herein should be adjusted as appropriate.

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1.5 Referenced Standards and Specifications

The following standards and specifications are referenced herein:

American Institute of Steel Construction

Specification for Structural Steel Buildings, June 22, 2010

American National Standards Institute

ANSI/ASME B18.2.6-10 *Fasteners for Use in Structural Applications*

ASTM International

ASTM A123-13 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

ASTM A194-14 *Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High-Temperature Service, or Both*

ASTM A325-14 *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*

ASTM A490-12 *Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength*

ASTM A563-07a(2014) *Standard Specification for Carbon and Alloy Steel Nuts*

ASTM B695-04(2009) *Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel*

ASTM F436-11 *Standard Specification for Hardened Steel Washers*

ASTM F959-13 *Standard Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners*

ASTM F1136-11 *Standard Specification for Zinc/Aluminum Corrosion Protective Coatings for Fasteners*

ASTM F1852-14 *Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/Washer Assemblies, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*

ASTM F2280-14 *Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/Washer Assemblies, Steel, Heat Treated, 150 ksi Minimum Tensile Strength*

ASTM F2329-13 *Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners*

American Society of Civil Engineers

ASCE 7-10 *Minimum Design Loads for Buildings and Other Structures*

IFI: Industrial Fastener Institute

IFI 144 (2000) *Test Evaluation Procedures for Coating Qualification Intended for Use on High-Strength Structural Bolts*

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SSPC: The Society for Protective Coatings

SSPC-PA2 (5/2012) *Measurement of Dry Coating Thickness With Magnetic Gages*

Commentary:

Familiarity with the referenced AISC, ASCE, ASME, ASTM and SSPC specification requirements is necessary for the proper application of this Specification. The discussion of referenced specifications in this Commentary is limited to only a few frequently overlooked or misunderstood items.

1.6 Drawing Information

The *Engineer of Record* shall specify the following information in the contract documents:

- (1) The ASTM designation and type (Section 2) of bolt to be used;
- (2) The *joint* type (Section 4) and;
- (3) The required class of slip resistance if *slip-critical joints* are specified (Section 4).

Commentary:

A summary of the information that the *Engineer of Record* is required to provide in the contract documents is provided in this Section. The parenthetical reference after each listed item indicates the location of the actual requirement in this Specification. In addition, the approval of the *Engineer of Record* is required in this Specification in the following cases:

- (1) For the reuse of non-galvanized ASTM A325 bolts (Section 2.3.3);
- (2) For the use of alternative washer-type indicating devices that differ from those that meet the requirements of ASTM F959, including the corresponding installation and inspection requirements that are provided by the *manufacturer* (Section 2.6.2);
- (3) For the use of alternative-design fasteners, including the corresponding installation and inspection requirements that are provided by the *manufacturer* (Section 2.8);
- (4) For the use of faying-surface coatings in *slip-critical joints* that provide a *mean slip coefficient* determined per Appendix A, but differing from Class A or Class B (Section 3.2.2(b));
- (5) For the use of thermal cutting of bolt holes produced free hand or for use in cyclically loaded joints (Section 3.3);
- (6) For the use of oversized (Section 3.3.2), short-slotted (Section 3.3.3) or long slotted holes (Section 3.3.4) in lieu of standard holes;
- (7) For the use of a value of D_u other than 1.13 (Section 5.4).

SECTION 2. FASTENER COMPONENTS

2.1. Manufacturer Certification of Fastener Components

Manufacturer certifications documenting conformance to the applicable specifications required in Sections 2.3 through 2.8 for all fastener components used in the *fastener assemblies* shall be available to the *Engineer of Record* and *inspector* prior to assembly or erection of structural steel.

Commentary:

Certification by the *manufacturer* or *supplier* of *high-strength bolts*, nuts, washers and other components of the *fastener assembly* is required to ensure that the components to be used are identifiable and meet the requirements of the applicable ASTM Specifications.

2.2. Storage of Fastener Components

Fastener components shall be protected from dirt and moisture in closed containers at the site of installation. Only as many fastener components as are anticipated to be installed during the work shift shall be taken from *protected storage*. Fastener components that are not incorporated into the work shall be returned to *protected storage* at the end of the work shift. Fastener components shall not be cleaned or modified from the as-delivered condition.

Fastener components that accumulate rust or dirt shall not be incorporated into the work unless they are requalified as specified in Section 7. ASTM F1852 and F2280 twist-off-type tension-control bolt assemblies and alternative-design fasteners that meet the requirements in Section 2.8 shall not be relubricated, except by the *manufacturer*.

Commentary:

Protected storage requirements are specified for *high-strength bolts*, nuts, washers and other fastener components with the intent that the condition of the components be maintained as nearly as possible to the as-manufactured condition until they are installed in the work. This involves:

- (1) The storage of the fastener components in closed containers to protect from dirt and corrosion;
- (2) The storage of the closed containers in a protected shelter;
- (3) The removal of fastener components from *protected storage* only as necessary; and,
- (4) The prompt return of unused fastener components to *protected storage*.

To facilitate manufacture, prevent corrosion and facilitate installation, the *manufacturer* may apply various coatings and oils that are present in the as-manufactured condition. As such, the condition of supplied fastener components or the *fastener assembly* should not be altered to make them unsuitable for pretensioned installation.

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If fastener components become dirty, rusty, or otherwise have their as-received condition altered, they may be unsuitable for pretensioned installation. It is also possible that a *fastener assembly* may not pass the pre-installation verification requirements of Section 7. Except for ASTM F1852 and F2280 twist-off-type tension-control bolt assemblies (Section 2.7) and some alternative-design fasteners (Section 2.8), fastener components can be cleaned and lubricated by the fabricator or the erector. Because the acceptability of their installation is dependent upon specific lubrication, ASTM F1852 and F2280 twist-off-type tension-control bolt assemblies and some alternative-design fasteners are suitable only if the *manufacturer* lubricates them.

2.3. Heavy-Hex Structural Bolts

- 2.3.1. Specifications: Heavy-hex structural bolts shall meet the requirements of ASTM A325 or ASTM A490. The *Engineer of Record* shall specify the ASTM designation and type of bolt (see Table 2.1) to be used.
- 2.3.2. Geometry: Heavy-hex structural bolt dimensions shall meet the requirements of ANSI/ASME B18.2.6. The bolt length used shall be such that the end of the bolt extends beyond or is at least flush with the outer face of the nut when properly installed.
- 2.3.3. Reuse: ASTM A490 bolts, ASTM F1852 and F2280 twist-off-type tension-control bolt assemblies, and galvanized or Zn/Al Inorganic coated ASTM A325 bolts shall not be reused. When approved by the *Engineer of Record*, black ASTM A325 bolts are permitted to be reused. Touching up or re-tightening bolts that may have been loosened by the installation of adjacent bolts shall not be considered to be a reuse.

Commentary:

ASTM A325 and ASTM A490 currently provide for two types (according to metallurgical classification) of *high-strength bolts*, supplied in diameters from ½ in. to 1½ in. inclusive. Type 1 covers medium carbon steel for ASTM A325 bolts and alloy steel for ASTM A490 bolts. Type 3 covers *high-strength bolts* that have improved atmospheric corrosion resistance and weathering characteristics. (Reference to Type 2 ASTM A325 and Type 2 A490 bolts, which appeared in previous editions of this Specification, has been removed following the removal of similar reference within the ASTM A325 and A490 Specifications). When the bolt type is not specified, either Type 1 or Type 3 may be supplied at the option of the *manufacturer*. Note that ASTM F1852 and ASTM F2280 twist-off-type tension-control bolt assemblies may be manufactured with a button head or hexagonal head; other requirements for these *fastener assemblies* are found in Section 2.7.

**Table 2.1. Acceptable ASTM A563 Nut Grade and Finish
and ASTM F436 Washer Type and Finish**

ASTM Desig.	Bolt Type	Bolt Finish ^d	ASTM A563 Nut Grade and Finish ^d	ASTM F436 Washer Type and Finish ^{a,d}
A325	1	Plain (uncoated)	C, C3, D, DH ^c and DH3; plain	1; plain
		Galvanized	DH ^c ; galvanized and lubricated	1; galvanized
		Zn/Al Inorganic, per ASTM F1136 Grade 3	DH ^c ; Zn/Al Inorganic, per ASTM F1136 Grade 5	1; Zn/Al Inorganic, per ASTM F1136 Grade 3
	3	Plain	C3 and DH3; plain	3; plain
F1852	1	Plain (uncoated)	C, C3, DH ^c and DH3; plain	1; plain ^b
		Mechanically Galvanized	DH ^c ; mechanically galvanized and lubricated	1; mechanically galvanized ^b
	3	Plain	C3 and DH3; plain	3; plain ^b
A490	1	Plain	DH ^c and DH3; plain	1; plain
		Zn/Al Inorganic, per ASTM F1136 Grade 3	DH ^c ; Zn/Al Inorganic, per ASTM F1136 Grade 5	1; Zn/Al Inorganic, per ASTM F1136 Grade 3
	3	Plain	DH3; plain	3; plain
F2280	1	Plain	DH ^c and DH3; plain	1; plain ^b
	3	Plain	DH3; plain	3; plain ^b
^a Applicable only if washer is required in Section 6. ^b Required in all cases under nut per Section 6. ^c The substitution of ASTM A194 grade 2H nuts in place of ASTM A563 grade DH nuts is permitted. ^d "Galvanized" as used in this table refers to hot-dip galvanizing in accordance with ASTM F2329 or mechanical galvanizing in accordance with ASTM B695. ^e "Zn/Al Inorganic" as used in this table refers to application of a Zn/Al Corrosion Protective Coating in accordance with ASTM F1136 which has met all the requirements of IFI-144.				

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Regular heavy-hex structural bolts and twist-off-type tension-control bolt assemblies are required by ASTM Specifications to be distinctively marked. Certain markings are mandatory. In addition to the mandatory markings, the *manufacturer* may apply additional distinguishing markings. The mandatory and sample optional markings are illustrated in Figure C-2.1.

ASTM Specifications permit the galvanizing of ASTM A325 bolts but not ASTM A490 bolts. Similarly, the application of zinc to ASTM A490 bolts by metallizing or mechanical coating is not permitted because the effect of mechanical galvanizing on embrittlement and delayed cracking of ASTM A490 bolts has not been fully investigated to date.

Bolt/Nut	Type 1	Type 3	
ASTM A325 bolt	 Three radial lines 120° apart are optional		
ASTM F1852 bolt	 Three radial lines 120° apart are optional		
ASTM A490 bolt			
ASTM F2280 bolt			
ASTM A563 nut	 Arcs indicate Grade C	 Arcs with "3" indicate Grade C3	 Grade D
	 Grade DH	 Grade DH3	
1. XYZ represents the manufacturer's identification mark. 2. ASTM F1852 and ASTM F2280 twist-off-type tension-control bolt assemblies are also produced with a heavy-hex head that has similar markings.			

Figure C-2.1. Required marks for acceptable bolt and nut assemblies.

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An extensive investigation conducted in accordance with IFI-144 was completed in 2006 and presented to the ASTM F16 Committee on Fasteners (F16 Research Report RR: F16-1001). The investigation demonstrated that Zn/Al Inorganic Coating, when applied per ASTM F1136 Grade 3 to ASTM A490 bolts, does not cause delayed cracking by internal hydrogen embrittlement, nor does it accelerate environmental hydrogen embrittlement by cathodic hydrogen absorption. It was determined that this is an acceptable finish to be used on Type 1 ASTM A325 and A490 bolts.

Although these bolts are typically not used in this manner, prior to embedding bolts coated with Zn/Al Inorganic Coating in concrete, it should be confirmed that there is no negative impact (to the bolt or the concrete) caused by the reaction of the intended concrete mix and the aluminum in the coating.

Galvanized *high-strength bolts* and nuts must be considered as a manufactured *fastener assembly*. Insofar as the hot-dip galvanized bolt and nut assembly is concerned, four principal factors must be considered so that the provisions of this Specification are understood and properly applied. These are:

- (1) The effect of the hot-dip galvanizing process on the mechanical properties of high-strength steels;
- (2) The effect of over-tapping for hot-dip galvanized coatings on the nut stripping strength;
- (3) The effect of galvanizing and lubrication on the torque required for pretensioning; and,
- (4) Shipping requirements.

Birkemoe and Herrschaft (1970) showed that, in the as-galvanized condition, galvanizing increases the friction between the bolt and nut threads as well as the variability of the torque-induced pretension. A lower required torque and more consistent results are obtained if the nuts are lubricated. Thus, it is required in ASTM A325 that a galvanized bolt and lubricated galvanized or Zn/Al Inorganic coated nut be assembled in a steel *joint* with an equivalently coated washer and tested by the *supplier* prior to shipment. This testing must show that the galvanized or Zn/Al Inorganic coated nut with the lubricant provided may be rotated from the snug-tight condition well in excess of the rotation required for pretensioned installation without stripping. This requirement applies to hot-dip galvanized, mechanically galvanized, and Zn/Al Inorganic coated fasteners. The above requirements clearly indicate that:

- (1) Galvanized and Zn/Al Inorganic coated *high-strength bolts* and nuts must be treated as a *fastener assembly*;
- (2) The *supplier* must supply nuts that have been lubricated and tested with the supplied *high-strength bolts*;
- (3) Nuts and *high-strength bolts* must be shipped together in the same shipping container; and,

- (4) The purchase of galvanized *high-strength bolts* and galvanized nuts from separate *suppliers* is not in accordance with the intent of the ASTM Specifications because the control of over-tapping, the testing and application of lubricant and the *supplier* responsibility for the performance of the assembly would clearly not have been provided as required.

Because some of the lubricants used to meet the requirements of ASTM Specifications are water soluble, it is advisable that galvanized *high-strength bolts* and nuts be shipped and stored in plastic bags or in sealed wood or metal containers. Containers of fasteners with hot-wax-type lubricants should not be subjected to heat that would cause depletion or change in the properties of the lubricant.

Both the hot-dip galvanizing process (ASTM F2329) and the mechanical galvanizing process (ASTM B695) are recognized in ASTM A325. The effects of the two processes upon the performance characteristics and requirements for proper installation are distinctly different. Therefore, distinction between the two must be noted in the comments that follow. In accordance with ASTM A325, all threaded components of the *fastener assembly* must be galvanized by the same process and the *supplier's* option is limited to one process per item with no mixed processes in a *lot*. Mixing *high-strength bolts* that are galvanized by one process with nuts that are galvanized by the other may result in an unworkable assembly.

Steels in the 200 ksi and higher tensile-strength range are subject to embrittlement if hydrogen is permitted to remain in the steel and the steel is subjected to high tensile stress. The minimum tensile strength of ASTM A325 bolts is 105 ksi or 120 ksi, depending upon the diameter, and maximum hardness limits result in production tensile strengths well below the critical range. The maximum tensile strength for ASTM A490 bolts was set at 170 ksi to provide a little more than a ten-percent margin below 200 ksi. However, because *manufacturers* must target their production slightly higher than the required minimum, ASTM A490 bolts close to the critical range of tensile strength must be anticipated. For black *high-strength bolts*, this is not a cause for concern. However, if the bolt is hot-dip galvanized, delayed brittle fracture in service is a concern because of the possibility of the introduction of hydrogen during the pickling operation of the hot-dip galvanizing process and the subsequent "sealing-in" of the hydrogen by the zinc coating. There also exists the possibility of cathodic hydrogen absorption arising from the corrosion process in certain aggressive environments.

ASTM A325 and A490 bolts are manufactured to dimensions as specified in ANSI/ASME B18.2.6. The basic dimensions, as defined in Figure C-2.2, are shown in Table C-2.1.

Table C-2.1. Bolt and Nut Dimensions

Nominal Bolt Diameter, d_b , in.	Heavy-Hex Bolt Dimensions, in.			Heavy-Hex Nut Dims., in.	
	Width across flats, F	Height, H_1	Thread Length, T	Width across flats, W	Height, H_2
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{5}{16}$	1	$\frac{7}{8}$	$\frac{31}{64}$
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{25}{64}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{39}{64}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{15}{32}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$\frac{47}{64}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{35}{64}$	$1\frac{1}{2}$	$1\frac{7}{16}$	$\frac{55}{64}$
1	$1\frac{5}{8}$	$\frac{39}{64}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$\frac{63}{64}$
$1\frac{1}{8}$	$1\frac{13}{16}$	$1\frac{1}{16}$	2	$1\frac{13}{16}$	$1\frac{7}{64}$
$1\frac{1}{4}$	2	$\frac{25}{32}$	2	2	$1\frac{7}{32}$
$1\frac{3}{8}$	$2\frac{13}{16}$	$\frac{27}{32}$	$2\frac{1}{4}$	$2\frac{3}{16}$	$1\frac{11}{32}$
$1\frac{1}{2}$	$2\frac{3}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$1\frac{15}{32}$

The principal geometric features of heavy-hex structural bolts that distinguish them from bolts for general application are the size of the head and the unthreaded body length. The head of the heavy-hex structural bolt is specified to be the same size as a heavy-hex nut of the same nominal diameter so that the ironworker may use the same wrench or socket either on the bolt head and/or on the nut. With the specific exception of fully threaded ASTM A325T bolts as discussed below, heavy-hex structural bolts have shorter threaded lengths than bolts for general applications. By making the body length of the bolt the control dimension, it has been possible to exclude the thread from all shear planes when desirable, except for the case of thin outside parts adjacent to the nut.

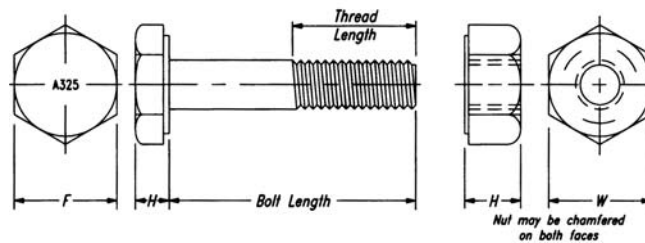


Figure C-2.2. Heavy-hex structural bolt and heavy-hex nut.

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The shorter threaded lengths provided with heavy-hex structural bolts tend to minimize the threaded portion of the bolt within the *grip*. Accordingly, care must also be exercised to provide adequate threaded length between the nut and the bolt head to enable appropriate installation without jamming the nut on the thread run-out.

Depending upon the increments of supplied bolt lengths, the full thread may extend into the *grip* for an assembly without washers by as much as $\frac{3}{8}$ in. for $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, $1\frac{1}{4}$, and $1\frac{1}{2}$ in. diameter *high-strength bolts* and as much as $\frac{1}{2}$ in. for 1, $1\frac{1}{8}$, and $1\frac{3}{8}$ in. diameter *high-strength bolts*. When the thickness of the ply closest to the nut is less than the $\frac{3}{8}$ in. or $\frac{1}{2}$ in. dimensions given above, it may still be possible to exclude the threads from the shear plane, when required, depending upon the specific combination of bolt length, *grip* and number of washers used under the nut (Carter, 1996). If necessary, the next increment of bolt length can be specified with ASTM F436 washers in sufficient number to both exclude the threads from the shear plane and ensure that the assembly can be installed with adequate threads included in the *grip* for proper installation.

At maximum accumulation of tolerances from all components in the *fastener assembly*, the thread run-out will cross the shear plane for the critical combination of bolt length and *grip* used to select the foregoing rules of thumb for ply thickness required to exclude the threads. This condition is not of concern, however, for two reasons. First, it is too unlikely that all component tolerances will accumulate at their maximum values to warrant consideration. Second, even if the maximum accumulation were to occur, the small reduction in shear strength due to the presence of the thread run-out (not a full thread) would be negligible.

There is an exception to the foregoing thread length requirements for ASTM A325 bolts, but not for ASTM A490 bolts, ASTM F1852 or ASTM F2280 twist-off-type tension-control bolt assemblies. Supplementary requirements in ASTM A325 permit the purchaser to specify a bolt that is threaded for the full length of the shank, when the bolt length is equal to or less than four times the nominal diameter. This exception is provided to increase economy through simplified ordering and inventory control in the fabrication and erection of some structures. It is particularly useful in those structures in which the strength of the *connection* is dependent upon the bearing strength of relatively thin connected material rather than the shear strength of the bolt, whether with threads in the shear plane or not. As required in ASTM A325, *high-strength bolts* ordered to such supplementary requirements must be marked with the symbol A325T.

To determine the required bolt length, the value shown in Table C-2.2 should be added to the *grip* (i.e., the total thickness of all connected material, exclusive of washers). For each ASTM F436 washer that is used, add $\frac{5}{32}$ in.; for each beveled washer, add $\frac{15}{16}$ in. The tabulated values provide appropriate allowances for manufacturing tolerances and also provide *sufficient thread*

Table C-2.2. Bolt Length Selection Increment

Nominal Bolt Diameter, d_b , in.	To Determine the Required Bolt Length, Add to Grip, in.
$\frac{1}{2}$	$\frac{1}{16}$
$\frac{5}{8}$	$\frac{7}{8}$
$\frac{3}{4}$	1
$\frac{7}{8}$	$1\frac{1}{8}$
1	$1\frac{1}{4}$
$1\frac{1}{8}$	$1\frac{1}{2}$
$1\frac{1}{4}$	$1\frac{5}{8}$
$1\frac{3}{8}$	$1\frac{3}{4}$
$1\frac{1}{2}$	$1\frac{7}{8}$

engagement with an installed heavy-hex nut. The length determined by the use of Table C-2.2 should be adjusted to the nearest $\frac{1}{4}$ -in. length increment ($\frac{1}{2}$ -in. length increment for lengths exceeding 6 in.). A more extensive table for bolt length selection based upon these rules is available (Carter, 1996).

Pretensioned installation involves the inelastic elongation of the portion of the threaded length between the nut and the thread run-out. ASTM A490 bolts and galvanized ASTM A325 bolts possess sufficient ductility to undergo one pretensioned installation, but are not consistently ductile enough to undergo a second pretensioned installation. Black ASTM A325 bolts, however, possess sufficient ductility to undergo more than one pretensioned installation as suggested in the *Guide* (Kulak et al., 1987). As a simple rule of thumb, a black ASTM A325 bolt is suitable for reuse if the nut can be run up the threads by hand.

2.4. Heavy-Hex Nuts

2.4.1. Specifications: Heavy-hex nuts shall meet the requirements of ASTM A563. The grade and finish of such nuts shall be as given in Table 2.1.

2.4.2. Geometry: Heavy-hex nut dimensions shall meet the requirements of ANSI/ASME B18.2.6.

Commentary:

Heavy-hex nuts are required by ASTM Specifications to be distinctively marked. Certain markings are mandatory. In addition to the mandatory markings, the *manufacturer* may apply additional distinguishing markings. The

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mandatory markings and sample optional markings are illustrated in Figure C-2.1.

Hot-dip galvanizing affects the stripping strength of the bolt-nut assembly because, to accommodate the relatively thick zinc coatings of non-uniform thickness on bolt threads, it is usual practice to hot-dip galvanize the blank nut and then to tap the nut over-size. This results in a reduction of thread engagement with a consequent reduction of the stripping strength. Only the stronger hardened nuts have adequate strength to meet ASTM thread strength requirements after over-tapping. Therefore, as specified in ASTM A325, only ASTM A563 grade DH are suitable for use as galvanized nuts. This requirement should not be overlooked if non-galvanized nuts are purchased and then sent to a local galvanizer for hot-dip galvanizing. Because the mechanical galvanizing process results in a more uniformly distributed and smooth zinc coating, nuts may be tapped over-size before galvanizing by an amount that is less than that required for the hot-dip process before galvanizing.

Despite the thin-film of the Zn/Al Inorganic Coating, tapping the nuts over-size may be necessary. Similar to mechanical galvanizing, the process results in a comparatively uniform and evenly distributed coating.

In earlier editions, this Specification permitted the use of ASTM A194 grade 2H nuts in the same finish as that permitted for ASTM A563 nuts in the following cases: with ASTM A325 Type 1 plain, Type 1 galvanized and Type 3 plain bolts and with ASTM A490 Type 1 plain bolts. Reference to ASTM A194 grade 2H nuts has been removed following the removal of similar reference within the ASTM A325 and A490 Specifications. However, it should be noted that ASTM A194 grade 2H nuts remain acceptable in these applications as indicated by footnote in Table 2.1, should they be available.

ASTM A563 nuts are manufactured to dimensions as specified in ANSI/ASME B18.2.6. The basic dimensions, as defined in Figure C-2.2, are shown in Table C-2.1

2.5. Washers

Flat circular washers and square or rectangular beveled washers shall meet the requirements of ASTM F436, except as provided in Table 6.1. The type and finish of such washers shall be as given in Table 2.1.

2.6. Washer-Type Indicating Devices

The use of washer-type indicating devices is permitted as described in Sections 2.6.1 and 2.6.2.

- 2.6.1. Compressible-Washer-Type Direct Tension Indicators: Compressible-washer-type direct tension indicators shall meet the requirements of ASTM F959.
- 2.6.2. Alternative Washer-Type Indicating Devices: When approved by the *Engineer of Record*, the use of alternative washer-type indicating devices that differ from those that meet the requirements of ASTM F959 is permitted.

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Detailed installation instructions shall be prepared by the *manufacturer* in a supplemental specification that is approved by the *Engineer of Record* and shall provide for:

- (1) The required character and frequency of pre-installation verification;
- (2) The alignment of bolt holes to permit insertion of the bolt without undue damage to the threads;
- (3) The placement of *fastener assemblies* in all types and sizes of holes, including placement and orientation of the alternative and regular washers;
- (4) The systematic assembly of the *joint*, progressing from the most rigid part of the *joint* until the connected plies are in *firm contact*; and,
- (5) The 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.

Detailed inspection instructions shall be prepared by the *manufacturer* in a supplemental specification that is approved by the *Engineer of Record* and shall provide for:

- (1) Observation of the required pre-installation verification testing; and,
- (2) Subsequent *routine observation* to ensure the proper use of the alternative washer-type indicating device.

2.7. Twist-Off-Type Tension-Control Bolt Assemblies

2.7.1. Specifications: Twist-off-type tension-control bolt assemblies shall meet the requirements of ASTM F1852 or F2280. The *Engineer of Record* shall specify the type of bolt (Table 2.1) to be used.

2.7.2. Geometry: Twist-off-type tension-control bolt assembly dimensions shall meet the requirements of ASTM F1852 or ASTM F2280. The bolt length used shall be such that the end of the bolt extends beyond or is at least flush with the outer face of the nut when properly installed.

Commentary:

It is the policy of the Research Council on Structural Connections to directly recognize only those fastener components that are manufactured to meet the requirements in an approved ASTM specification. Prior to this edition, the RCSC Specification provided for the use of ASTM A325 and A490 bolts, and F1852 twist-off-type tension-control bolt assemblies directly and alternative-design fasteners meeting detailed requirements similar to those in Section 2.8 when approved by the *Engineer of Record*. With this edition, ASTM F2280 twist-off-type tension-control bolt assemblies are now recognized directly. Essentially, ASTM F2280 relates an ASTM A490-equivalent product to a specific method of installation that is suitable for use in all *joint* types as described in Section 8. Provision has also been retained for approval by the

Engineer of Record of other alternative-design fasteners that meet the detailed requirements in Section 2.8.

If galvanized, ASTM F1852 twist-off-type tension-control bolt assemblies are required in ASTM F1852 to be mechanically galvanized.

2.8. Alternative-Design Fasteners

When approved by the *Engineer of Record*, the use of alternative-design fasteners is permitted if they:

- (1) Meet the materials, manufacturing and chemical composition requirements of ASTM A325 or ASTM A490, as applicable;
- (2) Meet the mechanical property requirements of ASTM A325 or ASTM A490 in full-size tests;
- (3) Have a body diameter and bearing area under the bolt head and nut that is equal to or greater than those provided by a bolt and nut of the same nominal dimensions specified in Sections 2.3 and 2.4; and,
- (4) Are supplied and used in the work as a *fastener assembly*.

Such alternative-design fasteners are permitted to differ in other dimensions from those of the specified *high-strength bolts* and nuts.

Detailed installation instructions shall be prepared by the *manufacturer* in a supplemental specification that is approved by the *Engineer of Record* and shall provide for:

- (1) The required character and frequency of pre-installation verification;
- (2) The alignment of bolt holes to permit insertion of the alternative-design fastener without undue damage;
- (3) The placement of *fastener assemblies* in all holes, including any washer requirements as appropriate;
- (4) The systematic assembly of the *joint*, progressing from the most rigid part of the *joint* until the connected plies are in *firm contact*; and,
- (5) The subsequent systematic pretensioning of all *fastener assemblies* in the *joint*, progressing from the most rigid part of the *joint* in a manner that will minimize relaxation of previously pretensioned bolts.

Detailed inspection instructions shall be prepared by the *manufacturer* in a supplemental specification that is approved by the *Engineer of Record* and shall provide for:

- (1) Observation of the required pre-installation verification testing; and,
- (2) Subsequent *routine observation* to ensure the proper use of the alternative-design fastener.

SECTION 3. BOLTED PARTS

3.1. Connected Plies

All connected plies that are within the *grip* of the bolt and any materials that are used under the head or nut shall be steel with faying surfaces that are uncoated, coated or galvanized as defined in Section 3.2. Compressible materials shall not be placed within the *grip* of the bolt. The slope of the surfaces of parts in contact with the bolt head and nut shall be equal to or less than 1:20 with respect to a plane that is normal to the bolt axis.

Commentary:

The presence of gaskets, insulation or any compressible materials other than the specified coatings within the *grip* would preclude the development and/or retention of the installed pretensions in the bolts, when required.

ASTM A325, A490, F1852, and F2280 bolt assemblies are ductile enough to deform to a surface with a slope that is less than or equal to 1:20 with respect to a plane normal to the bolt axis. Greater slopes are undesirable because the resultant localized bending decreases both the strength and the ductility of the bolt.

3.2. Faying Surfaces

Faying surfaces and surfaces adjacent to the bolt head and nut shall be free of dirt and other foreign material. Additionally, *faying surfaces* shall meet the requirements in Sections 3.2.1 or 3.2.2.

- 3.2.1. *Snug-Tightened Joints* and *Pretensioned Joints*: The *faying surfaces* of *snug-tightened joints* and *pretensioned joints* as defined in Sections 4.1 and 4.2 are permitted to be uncoated, coated with coatings of any formulation or galvanized.

Commentary:

In both *snug-tightened joints* and *pretensioned joints*, the ultimate strength is dependent upon shear transmitted by the bolts and bearing of the bolts against the connected material. It is independent of any frictional resistance that may exist on the *faying surfaces*. Consequently, since slip resistance is not an issue, the *faying surfaces* are permitted to be uncoated, coated, or galvanized without regard to the resulting slip coefficient obtained.

For pretensioned joints, caution should be used in the specification and application of thick coatings within the *faying surface*. Although slip resistance is not required, fastener assemblies in joints with thick or multi-layer coatings may exhibit significant loss of pretension because of compressive creep in softer coatings such as epoxies, alkyds, vinyls, acrylics, and urethanes. Previous bolt relaxation studies have been conducted using uncoated steel with black bolts or galvanized steel with galvanized bolts. Galvanized surfaces ranged up to approximately 4 mils of thickness, of which approximately half the thickness

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was the compressible soft pure zinc surface layer. The underlying zinc-iron layers are very hard and would exhibit little creep. See *Guide*, Section 4.4. Tests have indicated that significant bolt pretension may be lost when the total coating thickness within the joint approaches 15 mils per surface, and that surface coatings beneath the bolt head and nut can contribute to additional reduction in pretension.

3.2.2 *Slip-Critical Joints*: The *faying surfaces* of *slip-critical joints* as defined in Section 4.3, including those of filler plates and finger shims, shall meet the following requirements:

- (1) *Uncoated Faying Surfaces*: *Uncoated faying surfaces* shall be free of scale, except tight mill scale, and free of coatings, including inadvertent overspray, in areas closer than one bolt diameter but not less than 1 in. from the edge of any hole and in all areas within the bolt pattern or shall be blast cleaned (Class B).
- (2) *Coated Faying Surfaces*: *Coated faying surfaces* shall first be blast cleaned and subsequently coated with a coating that is qualified in accordance with the requirements in Appendix A as a Class A or Class B coating as defined in Section 5.4. Alternatively, when approved by the *Engineer of Record*, coatings that provide a *mean slip coefficient* that differs from Class A or Class B are permitted when:
 - (i) The *mean slip coefficient* μ is established by testing in accordance with the requirements in Appendix A; and,
 - (ii) The design slip resistance is determined in accordance with Section 5.4 using this coefficient, except that, for design purposes, a value of μ greater than 0.50 shall not be used.

The plies of *slip-critical joints* with *coated faying surfaces* shall not be assembled before the coating has cured for the minimum time that was used in the qualifying tests.

- (3) *Galvanized Faying Surfaces*: *Galvanized faying surfaces* shall first be hot dip galvanized in accordance with the requirements of ASTM A123 and subsequently roughened by means of hand wire brushing. Power wire brushing is not permitted. When prepared by roughening, the *galvanized faying surface* is designated as Class C for design.

Commentary:

Slip-critical joints are those *joints* that have specified *faying surface* conditions that, in the presence of the clamping force provided by pretensioned fasteners, resist a design load solely by friction and without displacement at the *faying*