MANUAL
OF STEEL
CONSTRUCTION

LOAD & RESISTANCE FACTOR DESIGN

Volume II

Connections

Second Edition

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FOREWORD

The American Institute of Steel Construction, founded in 1921, is the non-profit technical specifying and trade organization for the fabricated structural steel industry in the United States. Executive and engineering headquarters of AISC are maintained in Chicago, Illinois.

The Institute is supported by three classes of membership: Active Members totaling 400 companies engaged in the fabrication and erection of structural steel, Associate Members who are allied product manufacturers, and Professional Members who are individuals or firms engaged in the practice of architecture or engineering. Professional members also include architectural and engineering educators. The continuing financial support and active participation of Active Members in the engineering, research, and development activities of the Institute make possible the publishing of this Second Edition of the *Load and Resistance Factor Design Manual of Steel Construction.*

The Institute's objectives are to improve and advance the use of fabricated structural steel through research and engineering studies and to develop the most efficient and economical design of structures. It also conducts programs to improve product quality.

To accomplish these objectives the Institute publishes manuals, textbooks, specifications, and technical booklets. Best known and most widely used are the *Manuals of Steel Construction,* LRFD (Load and Resistance Factor Design) and ASD (Allowable Stress Design), which hold a highly respected position in engineering literature. Outstanding among AISC standards are the *Specifications for Structural Steel Buildings* and the *Code of Standard Practice for Steel Buildings and Bridges.*

The Institute also assists designers, contractors, educators, and others by publishing technical information and timely articles on structural applications through two publications, *Engineering Journal* and *Modern Steel Construction.* In addition, public appreciation of aesthetically designed steel structures is encouraged through its award programs: Prize Bridges, Architectural Awards of Excellence, Steel Bridge Building Competition for Students, and student scholarships.

Due to the expanded nature of the material, the Second Edition of the LRFD Manual has been divided into two complementary volumes. Volume I contains the LRFD Specification and Commentary, tables, and other design information for structural members. Volume II contains all of the information on connections. Like the LRFD Specification upon which they are based, both volumes of this LRFD Manual apply to buildings, not bridges.

The Committee gratefully acknowledges the contributions of Roger L. Brockenbrough, Louis F. Geschwindner, Jr., and Cynthia J. Zahn to this Manual.

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REFERENCED SPECIFICATIONS, CODES, AND STANDARDS

Part 6 (Volume I) of this LRFD Manual contains the full text of the following:

American Institute of Steel Construction, Inc. (AISC)
Load and Resistance Factor Design Specification for Structural Steel Buildings, December 1, 1993
Specification for Load and Resistance Factor Design of Single-Angle Members, December 1, 1993
Seismic Provisions for Structural Steel Buildings, June 15, 1992
Code of Standard Practice for Steel Buildings and Bridges, June 10, 1992

Research Council on Structural Connections (RCSC)
Load and Resistance Factor Design Specifications for Structural Joints Using ASTM A325 or A490 Bolts, June 8, 1988

Additionally, the following other documents are referenced in Volumes I and II of the LRFD Manual:

American Association of State Highway and Transportation Officials (AASHTO)
AASHTO/AWS D1.5–88

American Concrete Institute (ACI)
ACI 349–90

American Iron and Steel Institute (AISI)
Load and Resistance Factor Design Specification for Cold-Formed Steel Structural Members, 1991

American National Standards Institute (ANSI)

ANSI/ASME B1.1–82	ANSI/ASME B18.2.2–86
ANSI/ASME B18.1–72	ANSI/ASME B18.5–78
ANSI/ASME B18.2.1–81	

American Society of Civil Engineers (ASCE)
ASCE 7-88

American Society for Testing and Materials (ASTM)

ASTM A6–91b	ASTM A490–91	ASTM A617–92
ASTM A27–87	ASTM A500–90a	ASTM A618–90a
ASTM A36–91	ASTM A501–89	ASTM A668–85a
ASTM A53–88	ASTM A502–91	ASTM A687–89
ASTM A148–84	ASTM A514–91	ASTM A709–91
ASTM A153–82	ASTM A529–89	ASTM A770–86
ASTM A193–91	ASTM A563–91c	ASTM A852–91
ASTM A194–91	ASTM A570–91	ASTM B695–91
ASTM A208(A239–89)	ASTM A572–91	ASTM C33–90
ASTM A242–91a	ASTM A588–91a	ASTM C330–89
ASTM A307–91	ASTM A606–91a	ASTM E119–88
ASTM A325–91c	ASTM A607–91	ASTM E380–91
ASTM A354–91	ASTM A615–92b	ASTM F436–91
ASTM A449–91a	ASTM A616–92	

American Welding Society (AWS)

AWS A2.4–93
AWS A5.1–91
AWS A5.5–81
AWS A5.17–89
AWS A5.18–79
AWS A5.20–79
AWS A5.23–90
AWS A5.25–91
AWS A5.28–79
AWS A5.29–80
AWS B1.0–77
AWS D1.1–92
AWS D1.4–92

PART 8

BOLTS, WELDS, AND CONNECTED ELEMENTS

OVERVIEW

Part 8 contains general information, design considerations, examples, and design aids for the design of bolts, anchor rods, other mechanical fasteners, welds, and connected elements in connections. It is based on the provisions of the 1993 LRFD Specification. Supplementary information may also be found in the Commentary on the LRFD Specification.

Following is a detailed overview of the topics addressed.

BOLTED CONSTRUCTION

High-Strength Bolts

LRFD Specification Section A3.3 permits the use of ASTM A325 and A490 high-strength bolts. ASTM A325 bolts are available in diameters from ½-in. to 1½-in. in two types. Type 1 medium-carbon-steel bolts are for general purpose use and use in elevated temperatures; they may be galvanized. Type 3 bolts offer improved atmospheric corrosion resistance and weathering characteristics similar to those of ASTM A242 or A588 steels.

ASTM A490 bolts are available in diameters from ½-in. to 1½-in. in two types. Type 1 bolts are alloy-steel bolts. Type 3 are alloy-steel bolts with improved atmospheric corrosion resistance and weathering characteristics similar to those of ASTM A242 or A588 steels. ASTM A490 bolts should not be galvanized and caution should be exercised if used in highly corrosive environments.

Type 2 (martensite) bolts, popular for many years, have been discontinued. Information on this type can be found in previous editions of the AISC *Manual of Steel Construction*.

When bolts of diameter larger than 1½ in. are required, ASTM A449 bolts are permitted to be used for snug-tightened and fully tensioned bearing-type connections; this material is not recognized in LRFD Specification Section A3.3 for use in slip-critical connections nor for use as bolts in diameters not greater than 1½ in. ASTM A449 bolts may be galvanized.

When an ASTM A449 bolt is used in tension or bearing and is tightened in excess of 50 percent of its minimum specified tensile strength, LRFD Specification Section J3.1 requires that an ASTM F436 washer be installed under the head of the bolt. The nut must be from the approved list in RCSC Specification Section 2(c). Since ASTM A325 nuts and washers for use with high-strength bolts are available only up to 1½-in. diameter, reference should be made to ASTM A563 for nuts and ASTM F436 for washers to select suitable sizes and grades for the intended application.

While ASTM A449 seems to be the equal of ASTM A325, there are two important differences which should be noted. First, ASTM A449 bolts are not produced to the same inspection and quality assurance requirements as ASTM A325 bolts. Second, ASTM A449 bolts are not produced to the same heavy-hex head and nut dimensions.

Alternative Design Bolts

RCSC Specification Section 2d permits the use of other fasteners when they meet the requirements as outlined therein. Figure 8-1 shows a tension-control or "twist-off" bolt which is installed with a special tool which twists off the splined end when the proper

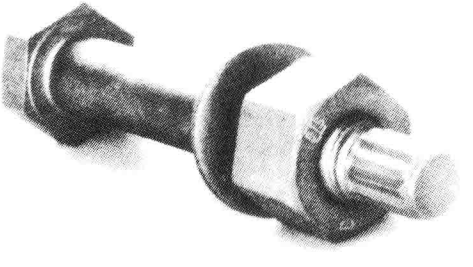


Fig. 8-1. Tension-control or "twist-off" bolt.

Table 8-1.
Compatability of High-Strength Bolts, Nuts, Washers

ASTM Bolt Desig.	Type	Coating	A563 Heavy Hex Nut Grade		F436 Washer Grade
			Recommended	Suitable	Recommended
A325	1	plain	C	C3, D, DH, DH3	1
		galvanized	DH	—	1
	3	plain	C3	DH3	3
A490	1	plain	DH	DH3	1
	3	plain	DH3	—	3
A449	1	plain	A	C, C3, D, DH, DH3	1
		galvanized	DH	D	1

bolt tension is achieved. Tension-control bolts are commonly available to meet the specifications of ASTM A325 and A490.

Compatible Nuts and Washers

The compatibility of ASTM A563 nuts and F436 washers with the aforementioned high-strength bolt specifications is as listed in Table 8-1. Alternatively, appropriate ASTM A194 nuts may be used. RCSC Specification Section 7c gives general requirements for when washers are required for high-strength bolts.

Economical Considerations

Since the material cost per unit of strength of ASTM A490 bolts is comparable with that of ASTM A325 bolts, it might seem more cost effective to reduce the number of bolts in a given connection by specifying ASTM A490 bolts. However, ASTM A490 bolts are more difficult to tighten and raise inventory and quality control issues associated with the use of multiple fastener grades; mixing of ASTM A325 and A490 bolts of the same diameter should be avoided to assure that the ASTM A490 bolts are installed in the proper location. Thus, the net benefit of specifying ASTM A490 bolts may be less than expected; cost ratios should be considered by the designer.

Similarly, cost ratios between grades of alternative design bolts will vary from those of conventional high-strength bolts. Thus, the decision regarding fastener selection will vary accordingly.

Regardless of the bolt type selected, the normal sizes of ¾-in., ⅞-in., and 1-in. diameter are usually preferred. Diameters above one inch are not commonly available, nor are they practical since special tools may be required to achieve fully tensioned installation.

Bearing-type connections should be specified whenever possible. Slip-critical connections with coatings other than clean mill scale incur appreciable extra costs associated with blasting, painting, drying, assembling, reblasting, and abrasion touch-up. If slip-critical connections are required for the proper serviceablity of the structure, care should be taken to avoid requiring the faying surfaces to be masked as this also contributes great

expense; coatings which provide a Class A or Class B slip coefficient may be an economical alternative to masking.

Dimensions and Weights

ASTM A325 and A490 bolts, A563 nuts, and F436 washers are given identifying marks as illustrated in Figure 8-2. A detailed description of identifying marks may be found in the RCSC Specification. Dimensions of ASTM A325 and A490 bolts, A563 nuts, and F436 washers are given and illustrated in Table 8-2. Threading dimensions of high-strength bolts are given in Table 8-7. Weights of conventional ASTM A325 and A490 bolts, A563 nuts, and F436 washers are given in Table 8-3. For dimensions and weights of tension-control ASTM A325 and A490 bolts, refer to manufacturers' literature or IFI. For dimensions and weights of ASTM A449 bolts, refer to Table 8-6.

Threads for high-strength bolts may be rolled or cut. Note that thread lengths for high-strength bolts are shorter than those for non-high-strength bolts. This allows the threads to be excluded from the shear plane when the thickness of the connected ply closest to the nut is as shown in Figure 8-3. While the RCSC Specification permits some thread run-out into the shear plane, it is important to provide sufficient thread to avoid jamming the nut into the run-out when tightening the bolt. Inspection controversy will be reduced by recognizing that bolts intentionally have a limited thread length, a manufacturing tolerance, and limited length increments; as with all manufactured items, dimensional tolerances must be considered.

The RCSC Specification recognizes these tolerances in two ways. First, additional washers are permitted to be used under the nut or under the head when circumstances permit. Second, there is no specified bolt "stick-through" requirement since only full-thread engagement of the nut is required; from RCSC Specification Section 2(b), "...The length of bolts shall be such that the end of the bolt will be flush with or outside the face of the nut when properly installed." A requirement for "stick-through", sometimes written in project specifications, increases the risk of jamming the nut on the thread run-out, and thus, of preventing tightening. A "stick-through" requirement will not enhance the performance of the bolt and should not be included in a project specification.

Alternatively, ASTM A325 bolts with length less than or equal to four times the nominal diameter may be ordered as fully threaded with the designation ASTM A325 T. Fully threaded ASTM A325 T bolts are not for use in bearing-type X connections since it would be impossible to exclude the threads from the shear plane. While this supplementary provision exists for ASTM A325 bolts, there is no similar supplementary provision made in ASTM A490 for full-length threading.

The ordered length of ASTM A325 and A490 bolts should be calculated as the grip (see Figure 8-2) plus the thickness of the washer(s) plus the allowance from Table 8-2. A thickness of $\frac{5}{32}$-in. for circular washers and $\frac{5}{16}$-in. for beveled washers should be provided per washer used; refer to the RCSC Specification for washer requirements. This total should be rounded to the next higher one-quarter inch. Note that bolts longer than five inches are generally available only in $\frac{1}{2}$-in. increments, except by special arrangement with the manufacturer or vendor. While longer lengths may be ordered, an 8-in. length is generally the maximum stock length available. Clipped washers are available for use in areas of tight clearance.

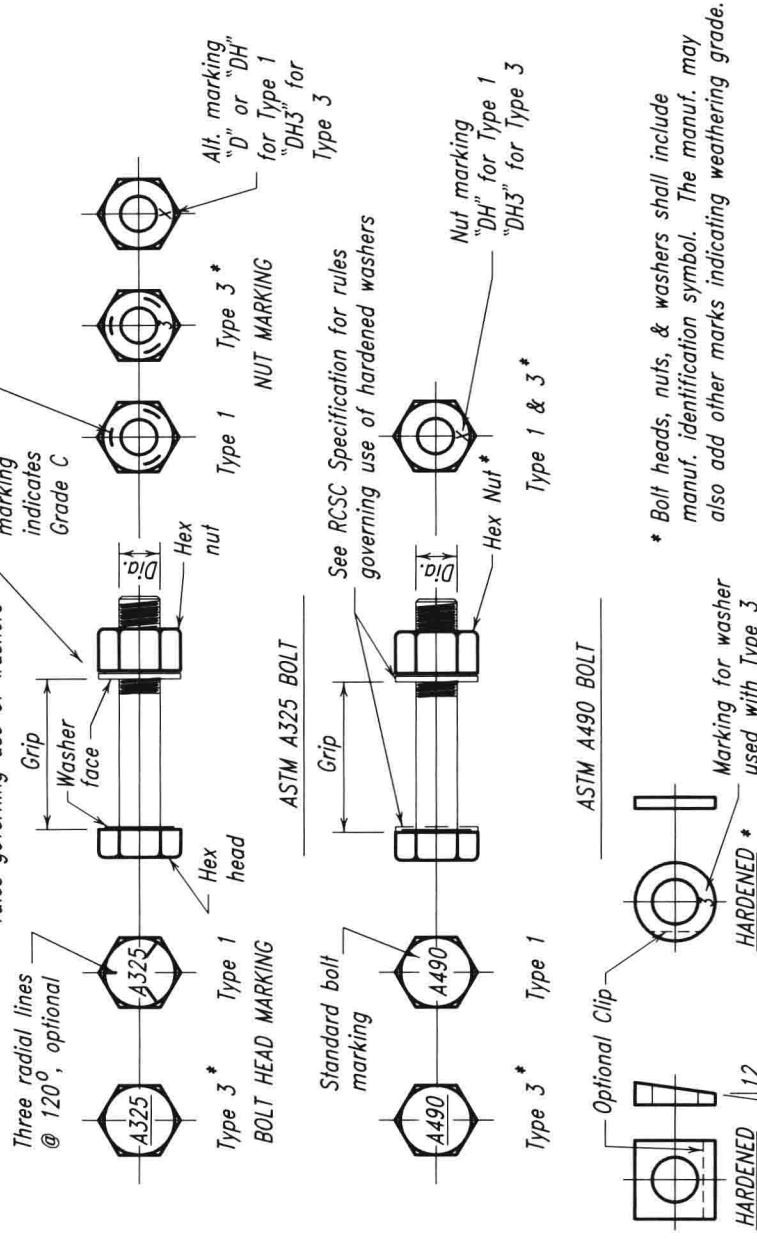
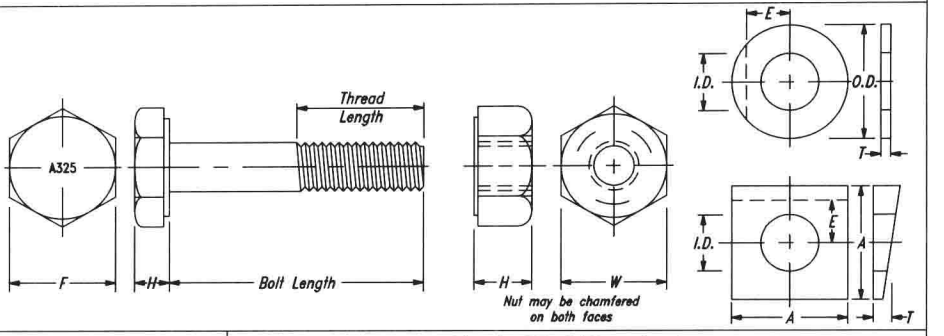


Fig. 8-2. Identifying high-strength bolts, nuts, and washers.

Table 8-2.
Dimensions of High-Strength Fasteners, in.



Measurement		Nominal Bolt Diameter, in.								
		1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
A325 and A490 Bolts[a]	Width Across Flats *F*	7/8	1 1/16	1 1/4	1 7/16	1 5/8	1 13/16	2	2 3/16	2 3/8
	Height *H*	5/16	25/64	15/32	35/64	39/64	11/16	25/32	27/32	15/16
	Thread Length	1	1 1/4	1 3/8	1 1/2	1 3/4	2	2	2 1/4	2 1/4
	Bolt Length[f] =Grip + →	11/16	7/8	1	1 1/8	1 1/4	1 1/2	1 5/8	1 3/4	1 7/8
A563 Nuts[b]	Width Across Flats *W*	7/8	1 1/16	1 1/4	1 7/16	1 5/8	1 13/16	2	2 3/16	2 3/8
	Height *H*	31/64	39/64	47/64	55/64	63/64	1 7/64	1 7/32	1 11/32	1 15/32
F436 Circular Washers[c]	Nom. Outside Diameter *OD*	1 1/16	1 5/16	1 15/32	1 3/4	2	2 1/4	2 1/2	2 3/4	3
	Nom. Inside Diameter *ID*	17/32	11/16	13/16	15/16	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8
	Thckns. *T* Max.	0.097	0.122	0.122	0.136	0.136	0.136	0.136	0.136	0.136
	Thckns. *T* Min.	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177
	Min. Edge Distance *E*[d]	7/16	9/16	21/32	25/32	7/8	1	1 3/32	1 7/32	1 5/16
F436 Square or Rect. Washers[c,e]	Min. Side Dimension *A*	1 3/4	1 3/4	1 3/4	1 3/4	1 3/4	2 1/4	2 1/4	2 1/4	2 1/4
	Mean Thckns. *T*	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16
	Taper in Thickness	2:12	2:12	2:12	2:12	2:12	2:12	2:12	2:12	2:12
	Min. Edge Distance *E*[d]	7/16	9/16	21/32	25/32	7/8	1	1 3/32	1 7/32	1 5/16

a Tolerances as specified in ASTM A325 and A490.
b Tolerances as specified in ASTM A563.
c ASTM F436 Washer Tolerances, in.:

Nominal Outside Diameter	−1/32; +1/32
Nominal Diameter of Hole	−0; +1/32
Flatness: max. deviation from straight-edge placed on cut side shall not exceed	0.010
Concentricity: center of hole to outside diameter (full indicator runout)	0.030
Burr shall not project above immediately adjacent washer surface more than	0.010

d For clipped washers only.
e For use with American standard beams (S) and channels (C).
f Tabular value does not include thickness of washer(s).