COMMENTARY ON HIGH-STRENGTH STRUCTURAL BOLTING

INTRODUCTION

Structural fasteners are widely used in today's assembly of bridges, buildings, highway construction and a host of other applications.

The high strength structural bolts which dominate most applications today are perhaps the most widely researched bolts which now exist. While the possibility of achieving a higher and more predictable clamping force was probably identified in the early 1900's, it was not until W. M. Wilson and F. P. Thomas reported the superior fatigue resistance of connections using high-strength bolts in a paper published in 1938 at the University of Illinois, that the potential was fully recognized.

Following World War II - 1947, an organization now known as the Research Council on Structural Connections (originally the Research Council on Riveted and Bolted Structural Joints), or RCSC, was formed to carry out cooperative research into the behavior of various types of structural connections joined with rivets and bolts. The very first project undertaken by this new Council was to evaluate the merits of high-strength bolts when compared with other types of fasteners. The results opened the door for increased use of structural bolts, and the subsequent 1951 publication of the first edition of, "Specifications for Structural Joints Using ASTM A325 Bolts". Further developments in the 1960's produced the A490 bolt and a range of structural bolting alternatives.

In 1976, IFI published a new standard identified as IFI-526, Metric High-Strength Structural Bolts, Nuts and Washers. This effort moved in parallel with international work being carried out by ISO Technical Committee 2 which initiated its effort in 1971. By 1980, ISO had completed its work and ASTM beginning in 1979 completed four needed mechanical and performance standards by 1983. ASME Standards Committee B18 completed and published in 1979 dimensional standards for metric heavy hex structural bolts and metric heavy hex nuts. The completion of these standards has made high-strength structural bolting an international practice.

North American Metric Standards

All of the required metric structural bolting practices are included in the following six standards developed for North American Practice:

- ASTM A325M, "High-Strength Bolts for Structural Steel Joints [Metric]", page F–16.
- ASTM A490M, "High-Strength Steel Bolts, Classes 10.9 and 10.9.3 for Structural Steel Joints [Metric]", page F–21.
- ASTM A563M, "Carbon and Alloy Steel Nuts [Metric]", page B–68.
- ANSI B18.2.3.7M, "Metric Heavy Hex Structural Bolts", page F–9.
- ANSI B18.2.4.6M, "Metric Heavy Hex Nuts", page D–29.
- ASTM F436M, "Hardened Steel Washers [Metric]", page J–42.
- ASTM F959M, "Compressible-Washer-Type Direct Tension Indicators for Use With Structural Fasteners [Metric]", page F–25.

Dimensions

For convenience, the basic dimensions of structural bolts, nuts, and flat circular washers are repeated in the following Tables 1, 2 and 3, respectively. Full requirements for each of these products may be found elsewhere in this book.

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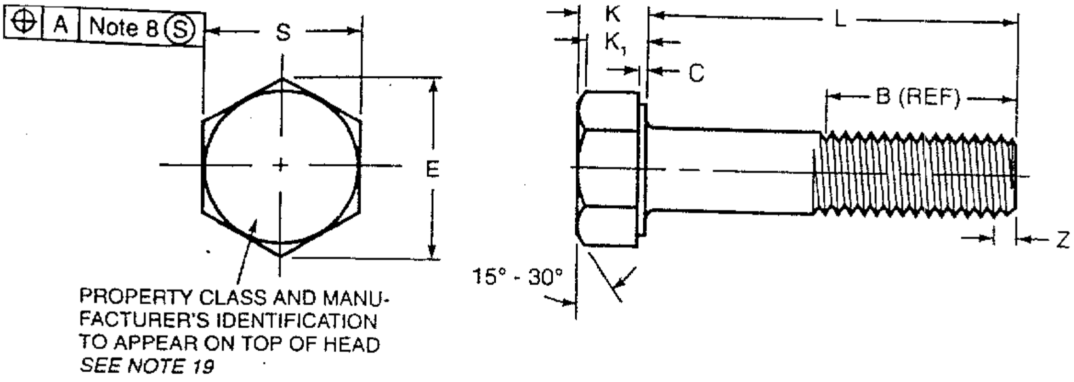


Table 1 Dimensions of Heavy Hex Structural Bolts (ANSI B18.2.3.7M)

D	S		E		K		B (Ref)	
Nominal Bolt Dia and Thread Pitch	Width Across Flats		Width Across Corners		Head Height		Thread Length	
							Bolt Lengths ≤ 100	Bolt Lengths > 100
	Max	Min	Max	Min	Max	Min	Basic	
M16 × 2	27.00	26.16	31.18	29.56	10.75	9.25	31	38
M20 × 2.5	34.00	33.00	39.26	37.29	13.40	11.60	36	43
M22 × 2.5	36.00	35.00	41.57	39.55	14.90	13.10	38	45
M24 × 3	41.00	40.00	47.34	45.20	15.90	14.10	41	48
M27 × 3	46.00	45.00	53.12	50.85	17.90	16.10	44	51
M30 × 3.5	50.00	49.00	57.74	55.37	19.75	17.65	49	56
M36 × 4	60.00	58.80	69.28	66.44	23.55	21.45	56	63

NOTE: For complete dimensional requirements, see page F–9.

Alternate types and styles of bolts, nuts and washers are recognized by the Research Council as being suited for use in structural joints. However, such products are proprietary and their dimensions, properties and performance features are not covered in national standards. Such information is available from the suppliers of these special products.

Bolt/Nut Selection Guidance

To assist designers to correctly select and use high strength structural bolts and nuts, seven topics are examined including, bolts, nuts, washers, plating, bolt/nut combinations, shear planes in joints, and bolt length/grip range relationships.

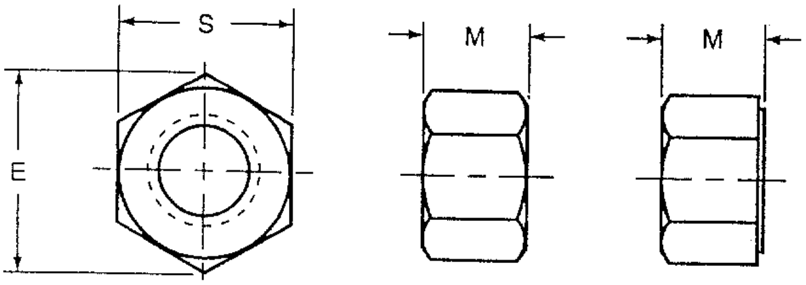


Table 2 Dimensions of Heavy Hex Nuts (ANSI B18.2.4.6M)

Nom Nut Dia and Thread Pitch	S		E		M	
	Width Across Flats		Width Across Corners		Thickness	
	Max	Min	Max	Min	Max	Min
M16 × 2	27.00	26.16	31.18	29.56	17.1	16.4
M20 × 2.5	34.00	33.00	39.26	37.29	20.7	19.4
M22 × 2.5	36.00	35.00	41.57	39.55	23.6	22.3
M24 × 3	41.00	40.00	47.34	45.20	24.2	22.9
M27 × 3	46.00	45.00	53.12	50.85	27.6	26.3
M30 × 3.5	50.00	49.00	57.74	55.37	30.7	29.1
M36 × 4	60.00	58.80	69.28	66.44	36.6	35.0

NOTE: For complete dimensional requirements, see page D–29.

(1) Bolts

A325M and A490M bolts are standard in 7 diameters, M16 thru M36. All bolts are heavy hex structural bolts with dimensions conforming to ANSI B18.2.3.7M, page F–9. All bolts have metric M profile threads (refer to ASME B1.13M, page A–20). Bolts with lengths up to 100 mm are available in 5 mm increments and 10 mm increments above 100 mm in length. Table 4 details the material types and surface finishes recognized in each specification.

(2) Nuts

Nuts for A325M and A490M bolts are heavy hex nuts with dimensions given in ANSI B18.2.4.6M, page D–29.

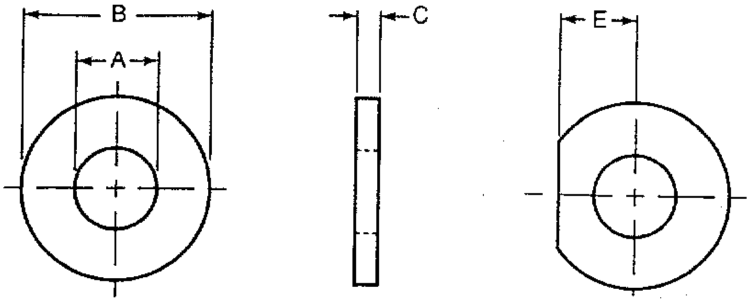
ASTM A563M, page B–68, covers the various strength grades of carbon steel nuts. The S in the designations is intended to denote structural application. Five Grades; 8S, 8S3, 10S, 10S3 and 10S (overtapped) are suited for use with A325M and/or A490M bolts. Table 5 details the various property classes.

(3) Washers

Hardened flat circular washers and clipped circular washers are included in ASTM F436M, page J–42.

The Research Council is currently developing a metric assembly specification. If it follows inch practices, it should detail rules regarding the use of hardened washers.

Current inch practice requires use of hardened steel washers when ASTM A325 bolts are tightened by techniques other than turn-of-nut method underneath the turned element. ASTM A490 inch series bolts also require a hardened washer under the turned element in tightening. Also, if the nonturned element bears against a material with a yield strength less than 276 MPa, washers are to be used.



Circular

Clipped Circular

Table 3 Circular and Clipped Washers for High-Strength Structural Bolts

Nominal Washer Size (Bolt Dia)	Flat Circular Washers						Clipped
	A		B		C		E
	Inside Diameter		Outside Diameter		Thickness		Width
	Max	Min	Max	Min	Max	Min	Min
16	18.4	18.0	34.0	32.4	4.6	3.1	14.0
20	22.5	22.0	42.0	40.4	4.6	3.1	17.5
22	24.5	24.0	44.0	42.4	4.6	3.4	19.2
24	26.5	26.0	50.0	48.4	4.6	3.4	21.0
27	30.5	30.0	56.0	54.1	4.6	3.4	23.6
30	33.6	33.0	60.0	58.1	4.6	3.4	26.2
36	39.6	39.0	72.0	70.1	4.6	3.4	31.5

NOTE: For complete dimensional requirements, refer to ASTM F436M, page J–42.

Additional rules for the use of washers are found in the Research Council specification available from IFI.

Compressible-washer-type direct tension indicators for use with structural fasteners are included in ASTM F959M, page F–25. Two types are provided for in this standard, which was first published in 1994.

(4) Platings

When corrosion resistant protection for A325M bolts and nuts is needed, the fasteners are normally either hot-dip galvanized (ASTM A153, page B–171) or provided with a mechanically deposited zinc coating (ASTM B695, page B–175). Rarely are A325M bolts electroplated or coated by chemical conversion methods.

ASTM A325M permits the plating of bolts made of either Type 1 or Type 2 steels. Type 3 steels, because of their "built in" corrosion protection, are supplied bare without any need for additive finishes. Suitable nuts for zinc coated A325M bolts are ASTM A563M Property Class 10S.

The Research Council on Structural Connections, supported by ASTM Committee F-16, strongly advises against galvanizing or zinc coating A490M bolts. The reason is their higher strength (and higher hardness) gives

Table 4 Metric High-Strength Structural Bolts

Item No.	Designation	Material Description	Surface Finish	Head Identification Marking
1	A325M, Type 1	Medium carbon steel, quenched and tempered	plain	A325M 8S
2	A325M, Type 2	Low carbon martensite steel, quenched and tempered	plain	A325M 8S
3	A325M, Type 3	Weathering steel, quenched and tempered	plain	A325M 8S3
4	A325M, Type 1	Medium carbon steel, quenched and tempered	galvanized	A325M 8S
5	A325M, Type 2	Low carbon martensite steel, quenched and tempered	galvanized	A325M 8S
6	A490M, Type 1	Alloy steel, quenched and tempered	plain	A490M 10S
7	A490M, Type 2	Low carbon martensite steel, quenched and tempered	plain	A490M 10S
8	A490M, Type 3	Weathering steel, quenched and tempered	plain	A490M 10S3
See Note 1	3		2, 3	4

NOTES:

1. Each Item No. is a combination of a material (specification number and steel type) and a surface finish.
2. "Galvanized" includes zinc coating by either the hot-dip or mechanical deposition method.
3. In the interests of potential economies to the purchaser, ASTM A325M and A490M provide for certain substitutions of bolt types and plating methods as follows:
    a) The purchaser retains the right to specify the material type and galvanizing process.
    b) For A325M plain bolts, if the purchaser does not specify the material type, the supplier, at his option, may furnish either Type 1 or Type 2; and further, if the purchaser agrees, the supplier may furnish Type 3.
    c) For A325M galvanized bolts, if the purchaser does not specify the material type, the supplier, at his option, may furnish either Type 1 or Type 2.
    d) For A325M galvanized bolts, if the purchaser does not specify the plating or coating method, the supplier, at his option, may supply hot-dip galvanized bolts or bolts with mechanically deposited zinc coatings.
    e) For A490M bolts, if the purchaser does not specify the material type, the supplier, at his option, may furnish Type 1, Type 2 or Type 3.
4. In addition to the identification markings shown in the table, all bolts must be marked with the manufacturer's symbol.

them an unacceptably high risk of embrittlement and the possibility of failure in service by stress corrosion. ASTM A490M prohibits the plating of bolts. When corrosion protection is needed, A490M Type 3 bolts should be considered.

The performance of hot-dip galvanized fasteners versus those with mechanically deposited zinc coatings has been under close examination for well over 25 years. Research has satisfactorily demonstrated an equivalency of

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Table 5 Metric Nuts for High-Strength Structural Bolts

Item No.	Designation	Material Description	Nut Identification Marking
A	A563M Property Class 8S	Carbon steel, may be heat treated	8S
B	A563M Property Class 8S3	Weathering steel, may be heat treated	8S3
C, CG	A563M Property Class 10S	Carbon steel, quenched and tempered	10S
D	A563M Property Class 10S3	Weathering steel, quenched and tempered	10S3
See Note 1	2		3

NOTES:

1. Single letter Item Nos. are grades of nuts furnished plain, i.e., nonplated or noncoated. Item Nos. suffixed with the letter "G" are the same grade of nut but furnished overtapped and either hot-dip galvanized or with a mechanically deposited zinc coating.
2. In the interests of potential economies to the purchaser, ASTM permits the supplier to furnish a stronger grade of nut as a substitute for the grade ordered, providing the purchaser is notified and agrees with the substitution.
3. In addition to the identification markings shown in the table, all nuts must be marked with the manufacturer's symbol.

corrosion protection of fasteners having an equal thickness of zinc coating. Substituting one for the other should not affect the ultimate survivability of a fastener in a corrosive atmosphere. However, it is well recognized that other concerns may influence a purchaser preference. Consequently, ASTM A325M carefully preserves the purchaser's right to specify which of the two deposition methods must be used. In the absence of purchaser instructions, the option reverts to the supplier. In such cases, competitive economics usually dictate the decision.

Plating increases the size (maximum material condition) of both externally and internally threaded fasteners. Standard zinc coatings deposited by either the hot-dip process or by mechanical deposition have an average thickness of about 50 µm. Consequently, without some adjustment of thread size, mating fasteners would not assemble.

High-strength structural bolt and nut plating practice is to plate standard bolts (having threads within Grade 6g tolerances before plat-

Table 6 High-Strength Bolt/Nut Combinations

Recommended Combinations		
Bolt	**Nut**	**Finish**
A325M, Type 1 A325M, Type 2	8S or 8S3 8S or 8S3	plain plain
A325M, Type 1 A325M, Type 2	10S 10S	zinc coated zinc coated
A325M, Type 3 A490M, Type 1	8S3 10S, 10S3	plain plain
A490M, Type 2 A490M, Type 3	10S, 10S3 10S3	plain plain

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ing) and to provide the needed assemblability by increasing the thread diameters of the internal thread by overtapping the nut. The diametral amounts that nuts are tapped oversize are specified in ASTM A563M. Normal practice is to tap hot-dip galvanized nuts following galvanizing and to tap mechanically deposited zinc coated nuts prior to coating. This means that the threads of galvanized nuts are bare, but this doesn't diminish corrosion protection because of the sacrificially supporting plating on the bolt threads, coupled with the sealing effect of high bolt preload.

(5) Bolt/Nut Combinations

Table 6 details recommended combinations within ASTM Specifications A325M-A490M, and A563M. Other combinations may be used based on provisions of respective standards.

(6) Shear Planes

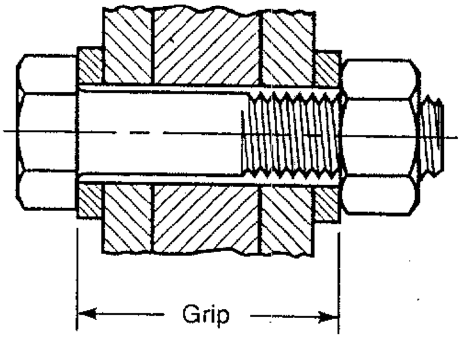
In bearing-type structural connections — those in which the service loads are supported in shear by the bolts — allowable shear stresses for the bolts are reduced by 30 percent if a shear plane occurs through its threaded section. Consequently, it is frequently important for the designer to check shear plane locations to learn where they occur in the bolt length. It is easily accomplished.

For each bolt length there is a specified body length. Body length is the minimum distance from the underhead bearing surface of the bolt to the last scratch of thread or top of the extrusion angle. This means that at least this length of full diameter unthreaded body is available.

By formula, the minimum body length equals the maximum grip gaging length (as computed) minus the maximum transition thread length (X): L_s min = L_g max – X max. Values are given in Table 2, page F–12. Using the specified body length, the designer can quickly check the location of shear planes in any joint.

(7) Bolt Length/Grip Range

Grip is defined as the total thickness of material, including washers, to be connected by the bolt. When washers are used, specified minimum washer thickness is added when computing the grip. To determine the grip range, two conditions must be examined. What is the absolute minimum thickness of material that a given bolt length can properly join, L_g min, and what is the maximum, L_g max?



Minimum Grip: L_g min

When computing the minimum grip, there must be a sufficient length of full thread within the grip to permit nut tightening without the possibility of advancing the nut thread into the incomplete thread at the bolt thread runout.

For each bolt length there is a grip gaging length (nominal length of bolt minus its nominal thread length). The grip gaging length is the maximum distance from the underhead bearing surface of the bolt to the face of a noncountersunk or noncounterbored GO thread ring gage assembled by hand on the bolt as far as the thread will permit. This means that a nut will always assemble freely on the bolt to at least this distance from the head.

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When washers are used, the reason why their specified minimum thickness is added into the grip is that if, when computing the grip, a washer thickness greater than its specified minimum is assumed and then, in the actual service application, minimum thickness washers are supplied, there is a risk the nut would advance into the bolt thread runout during tightening.

Maximum Grip: L_g max

When connecting the maximum grip, it is prudent to provide a modest stick-through of the bolt beyond the face of the nut. However, bolt/nut strength is normally adequate if the bolt end is flush with the nut face.

Consequently, if the extreme situation is assumed and if in this condition the bolt end is flush with the nut face, then under all other conditions there will be a positive stick-through.

The extreme situation is the combination of a bolt of permitted minimum length, a nut of maximum thickness, and a grip which includes two washers of maximum thickness. As stated earlier, when washers are used, it is important to add into the grip the specified minimum thickness of the washers. Consequently, when establishing the maximum grip that a bolt can accommodate, it is necessary to allow for the washer thickness tolerance of two washers on the assumption that maximum thickness washers may actually be supplied.

Bolt Installation

The basic principle of high strength structural bolting is that installed bolts be tightened to such high initial preloads that the resulting clamping action on the joint permits the transfer of the externally applied service loads through friction between the joint members rather than by bolt shear and bearing.

The Research Council on Structural Connections in its specification requires that A325 and A490 bolts be tightened to develop a minimum bolt tension equal to 70 percent of the bolt's specified minimum tensile strength. This means that following tightening, most bolts will be stressed beyond their yield strength.

By far the most popular method for installing high-strength structural bolts is the turn-of-nut method. Other techniques are tension control by wrench calibration, use of tension indicators, and use of proprietary type fasteners which have a built-in tension control mechanism.

(IFI Note: Recommended Reading: Mechanical Fasteners for Steel Bridges Vol. I, Chapter 4A Highway Structures Design Handbook, copies available from IFI or AISC.)