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COMMENTARY ON HIGH STRENGTH STRUCTURAL BOLTING

Introduction.

The Research Council on Structural Connections (originally known as the Research Council on Riveted and Bolted Structural Joints) was formed in 1947 to conduct cooperative research on the behavior of various types of structural connections joined with rivets and bolts. The first project undertaken by the Council was a study to evaluate the merits of high strength bolts in comparison with those of other types of fasteners then being used in structural connections. The results were sufficiently promising to encourage the Council to engage in extensive research on high strength bolted joints.

As the results of the Council's work became known, interest in using these bolts expanded greatly. In 1951, the Council recognized the need for authoritative guidance in the design, fabrication and assembly of high strength bolted joints, and it issued the first edition of "Specifications for Structural Joints Using ASTM A325 Bolts."

Through the years the research effort of the Council continued. Revisions of its assembly specification were released as new findings warranted. Each revision incorporated modifications, improvements and other technical advances for making high strength bolting easier, more reliable and considerably more economical.

In 1961, the Council in recognition of the expanding use of constructional alloy steels, particularly in bridges and other similar structures where the weight of the structure itself is extremely important, initiated a project to develop a new bolt with higher strength properties than those of the A325 bolt. Through Council supervised research, the behavior of structural joints assembled using alloy steel bolts, later to be known as A490 bolts, was studied. Based on the results of this work, a new practice was established and approved by the Council in 1964. This new practice, which is actually an extension of the A325 high strength bolting practice, was first documented in the March, 1964 edition of the Council's specification which at that time was retitled, "Specifications for Structural Joints Using ASTM A325 or A490 Bolts.

In 1970, the Council gave recognition to the use of hot dip galvanized A325 bolts and also to high-strength weathering steel fasteners. Designated as Type 3, high strength weathering steel bolts have weathering characteristics and atmospheric corrosion resistance comparable to that of ASTM A588 steels and A242 weathering steels when used in bare steel applications. Nuts and washers used in assemblies with these bolts also have comparable corrosion resistance and weathering characteristics.

In 1974, the Council-sponsored book, "Guide to Design Criteria for Bolted and Riveted Joints" by J. Fisher and J. Struik was published by John Wiley & Sons. This book presents a state-of-the-art summary of experimental, theoretical and field experience collected to that time and recommends procedures for designing structural joints using A325 and A490 bolts. A second edition of this book is now being prepared and should be published within the next several months.

High strength structural bolting is an international practice. In 1971, ISO Technical Committee 2 established a Working Group to develop ISO standards for the dimensions and mechanical properties of metric high strength structural bolts, nuts and hardened washers. The ISO work was essentially completed in 1980. ASME and ASTM committees then prepared the necessary standards for North American use, basing them on the ISO decisions. These documents are now all published in IFI's book METRIC FASTENER STANDARDS.

Documents.

All of the necessary information, requirements and guidance relating to inch-series high strength bolting practice — the design, fabrication, erection, and inspection of bolted structural connections — and the dimensions and properties of the applicable fasteners are collectively covered in the seven following documents.

- "Structural Joints Using ASTM A325 and A490 Bolts" issued by the Research Council on Structural Connections. Copies are available from Industrial Fasteners Institute and from the American Institute of Steel Construction.
- ASTM A325 "High-Strength Bolts for Structural Steel Joints," abstracted on page E-11.
- ASTM A490 "Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength," abstracted on page E-18.

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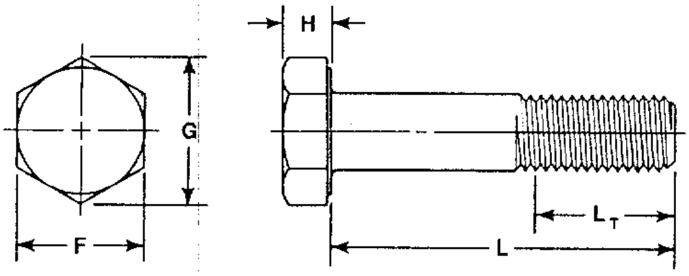

Table 1 Heavy Hex Structural Bolts (ANSI/ASME B18.2.1)

Nom Size and Threads Per Inch	F Width Across Flats		G Width Across Corners		H Height		L_T Thread Length
	Max	Min	Max	Min	Max	Min	Basic
1/2 - 13	0.875	0.850	1.010	0.969	0.323	0.302	1.00
5/8 - 11	1.062	1.031	1.227	1.175	0.403	0.378	1.25
3/4 - 10	1.250	1.212	1.443	1.383	0.483	0.455	1.38
7/8 - 9	1.438	1.394	1.660	1.589	0.563	0.531	1.50
1 - 8	1.625	1.575	1.876	1.796	0.627	0.591	1.75
1-1/8 - 7	1.812	1.756	2.093	2.002	0.718	0.658	2.00
1-1/4 - 7	2.000	1.938	2.309	2.209	0.813	0.749	2.00
1-3/8 - 6	2.188	2.119	2.526	2.416	0.878	0.810	2.25
1-1/2 - 6	2.375	2.300	2.742	2.622	0.974	0.902	2.25

Note: For complete dimensional requirements, see page E-34.

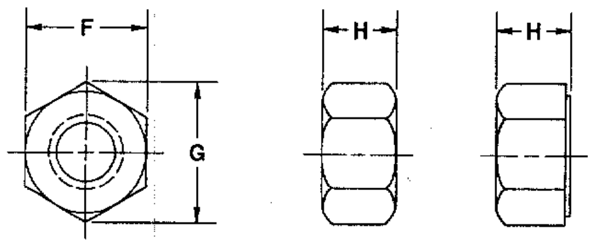

Table 2 Heavy Hex Nuts (ANSI/ASME B18.2.2)

Nom Size and Threads Per Inch	F Width Across Flats		G Width Across Corners		H Thickness	
	Max	Min	Max	Min	Max	Min
1/2 - 13	0.875	0.850	1.010	0.969	0.504	0.464
5/8 - 11	1.062	1.031	1.227	1.175	0.631	0.587
3/4 - 10	1.250	1.212	1.443	1.382	0.758	0.710
7/8 - 9	1.438	1.394	1.660	1.589	0.885	0.833
1 - 8	1.625	1.575	1.876	1.796	1.012	0.956
1-1/8 - 7	1.812	1.756	2.093	2.002	0.139	1.079
1-1/4 - 7	2.000	1.938	2.309	2.209	1.251	1.187
1-3/8 - 6	2.188	2.119	2.526	2.416	1.378	1.310
1-1/2 - 6	2.375	2.300	2.742	2.622	1.505	1.433

Note: For complete dimensional requirements, see page D-14.

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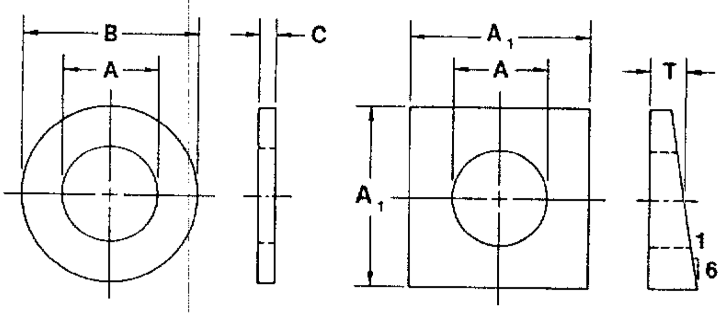

Table 3 Washers for High Strength Structural Bolts

Nom Washer Size (Bolt Dia)	Flat Circular Washers				Beveled Washers	
	A	B	C		A_1	T
	Inside Dia	Outside Dia	Thickness		Side Dimension	Mean Thickness
	Nom	Nom	Max	Min	Nom	Nom
1/2	0.531	1.062	0.177	0.097	1.750	0.312
5/8	0.688	1.312	0.177	0.122	1.750	0.312
3/4	0.812	1.469	0.177	0.122	1.750	0.312
7/8	0.938	1.750	0.177	0.136	1.750	0.312
1	1.125	2.000	0.177	0.136	1.750	0.312
1-1/8	1.250	2.250	0.177	0.136	2.250	0.312
1-1/4	1.375	2.500	0.177	0.136	2.250	0.312
1-3/8	1.500	2.750	0.177	0.136	2.250	0.312
1-1/2	1.625	3.000	0.177	0.136	2.250	0.312

Note: For complete dimensional requirements, refer to ASTM F436, page L-23.

- — ASTM A563 "Carbon and Alloy Steel Nuts," abstracted on page B-108.
- — ASTM F436 "Hardened Steel Washers," abstracted on page L-23.
- — ANSI/ASME B18.2.1 "Heavy Hex Structural Bolts," page E-34.
- — ANSI/ASME B18.2.2 "Heavy Hex Nuts," page D-14.

Dimensions.

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

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 proprietory 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, 7 topics are discussed — bolts, nuts, washers, plating, bolt/nut combinations, shear planes in joints, and bolt length/grip range relationships.

A. Bolts.

A325 and A490 bolts are standard in only 9 diameters, ½ thru 1½ in. All bolts are heavy hex structural bolts with dimensions conforming to those given in ANSI/ASME B18.2.1, page E-34. All bolts have Unified coarse threads. Bolts are available in ¼ in. length increments for all lengths.

ASTM A325, page E-11, recognizes that bolts can be made of 3 basic types of steel —

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Table 4 High Strength Structural Bolts

Item No.	Designation	Material Description	Surface Finish	Head Identification Marking
1	A325, Type 1	Medium carbon steel, quenched and tempered	plain	A325
2	A325, Type 2	Low carbon martensite steel, quenched and tempered	plain	A325
3	A325, Type 3	Weathering steel, quenched and tempered	plain	A325
4	A325, Type 1	Medium carbon steel, quenched and tempered	galvanized	A325
5	A325, Type 2	Low carbon martensite steel, quenched and tempered	galvanized	A325
6	A490, Type 1	Alloy steel, quenched and tempered	plain	A490
7	A490, Type 2	Low carbon martensite steel, quenched and tempered	plain	A490
8	A490, Type 3	Weathering steel, quenched and tempered	plain	A490
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 A325 and A490 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 A325 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 A325 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 A325 galvanized bolts, if the p;urchaser 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 A490 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.

Table 5 Nuts for High Strength Structural Bolts

Item No.	Designation	Material Description	Nut Identification Marking
A	A563, Grade C	Carbon steel, may be heat treated	
B	A563, Grade C3	Weathering steel, may be heat treated	
C	A563, Grade D	Carbon steel, may be heat treated	D
D, DG	A563, Grade DH	Carbon steel, quenched and tempered	DH
E	A563, Grade DH3	Weathering steel, quenched and tempered	DH3
F	A194/A194M, Grade 2	Carbon steel	2
G, GG	A194/A194M, Grade 2H	Carbon steel, quenched and tempered	2H
See Note 1	2		3

Notes:

1. Single letter Item Nos. are grades of nuts furnished plain, i.e. non-plated or non-coated. 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. ASTM A563 also permits the substitution of A194/A194M Grade 2 nuts for A563 Grades C or D nuts, and A194/A194M Grade 2H nuts for A563 Grades C, D, or DH nuts.
3. In addition to the identification markings shown in the table, all nuts must be marked with the manufacturer's symbol.

medium carbon steel (e.g. AISI 1035 or 1038), low carbon martensite steel (e.g. AISI 10B18 or 10B21), and atmospheric corrosion resistant steel, commonly known as "weathering" steel.

ASTM A490, page E-18, also recognizes 3 types of steel — carbon alloy steel (e.g. AISI 4037, 4140 and 8635), low carbon martensite steel (for sizes 1 in. and smaller only), and atmospheric corrosion resistant steel.

For fuller information on these various steel types, refer to page B-9.

Table 4 details the material types and surface finishes recognized in each specification. Footnotes explain the purchaser/supplier options with respect to material choice and plating methods.

B. Nuts.

Nuts for A325 and A490 bolts are heavy hex nuts with dimensions as given in ANSI/ASME B18.2.2, page D-14.

ASTM A563, page B-108, covers the various strength grades of carbon steel nuts. Five of its grades — C, C3, D, DH, and DH3 — are suited for use with A325 and/or A490 bolts. ASTM A194/A194M, page B-115, covers several grades of carbon and alloy steel nuts. Two of its grades — 2 and 2H — are frequently used with high strength structural bolts.

Table 5 details the various nut strength grades and explains, in footnotes, permissible substitutions.

C. Washers.

Hardened flat circular washers and beveled washers are covered in ASTM F436, page L-23.

The Research Council in its assembly specification specifies these rules regarding use of hardened washers —

1) When using A325 bolts, washers are not required if a) the holes in the outer plies are of standard size, b) fasteners are to be tightened using the turn-of-nut method, and c) neither outer face of the connected parts has a slope greater than

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1:20 with respect to a plane normal to the bolt axis.

2) A325 bolts tightened by techniques other than the turn-of-nut method shall have a hardened washer under the bolt head or nut whichever is the element turned in tightening.

3) When using A490 bolts, a hardened washer must be used under the element turned in tightening. Additionally, a hardened washer must be used under the non-turned element if the material against which it bears has a specified minimum yield strength less than 40 ksi.

4) Hardened washers of standard thickness shall be installed over oversize and short slotted holes in outer plies of the connected material. Hardened washers of special thickness (5/16 in. min) shall be installed over long slotted holes and also over oversize and short slotted holes when using A490 bolts of sizes 1-1/8 in. and larger.

5) A hardened beveled washer shall be used to compensate for lack of parallelism when an outer face has a slope greater than 1:20 with respect to a plane normal to the bolt axis.

D. Platings.

When corrosion resistant protection for A325 bolts and nuts is needed, the fasteners are normally either hot-dip galvanized (ASTM A153, page B-165) or provided with a mechanically deposited zinc coating (ASTM B695, page B-168). Rarely are A325 bolts electroplated or coated by chemical conversion methods.

ASTM A325 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 A325 bolts are ASTM A563 Grade DH or A194/A194M Grade 2H.

The Research Council on Structural Connections, supported by ASTM Committee F-16, strongly advises against galvanizing or zinc coating A490 bolts. The reason is their higher strength (and higher hardness) gives them an unacceptability high risk of embrittlement and the possibility of failure in service by stress corrosion. (Refer to page B-35 for a fuller discussion.) ASTM A490 prohibits the plating of bolts. When corrosion protection is needed, A490 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 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 A325 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 0.002 in. 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 Class 2A tolerances before plating) and to provide the needed assembleability 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 A563. 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.

For fuller information refer to page A-10 and B-44.

E. Bolt/Nut Combinations.

Table 6 details the various bolt/nut combinations permitted by ASTM Specifications A325, A490 and A563. The recommended combination

Table 6 High Strength Structural Bolt/Nut Combinations

Recommended Combinations				Alternative Combinations Item Nos.
Item Nos.	Description			
	Bolt	Nut	Finish	
1-A	A325, Type 1	A563, Grade C	Plain	1-B, 1-C, 1-D, 1-E, 1-F, 1-G 2-A, 2-B, 2-C, 2-D, 2-E, 2-F, 2-G 3-A, 3-B, 3-C, 3-D, 3-E, 3-F, 3-G
2-A	A325, Type 2	A563, Grade C	Plain	2-B, 2-C, 2-D, 2-E, 2-F, 2-G 1-A, 1-B, 1-C, 1-D, 1-E, 1-F, 1-G 3-A, 3-B, 3-C, 3-D, 3-E, 3-F, 3-G
3-B	A325, Type 3	A563, Grade C3	Plain	3-E
4-DG	A325, Type 1	A563, Grade DH	Galvanized	4-GG, 5-DG, 5-GG
5-DG	A325, Type 2	A563, Grade DH	Galvanized	5-GG, 4-DG, 4-GG
6-D	A490, Type 1	A563, Grade DH	Plain	6-E, 6-G, 7-D, 7-E, 7-G, 8-D, 8-E, 8-G
7-D	A490, Type 2	A563, Grade DH	Plain	7-E, 7-G, 6-D, 6-E, 6-G, 8-D, 8-E, 8-G
8-E	A490, Type 3	A563, Grade DH3	Plain	None

Note: Item No. numerals identify bolt types described in Table 4 and Item No. letters identify nut grades described in Table 5.

is a "first choice;" the alternate combinations are those permitted by the ASTM Specifications when purchaser/supplier options are exercised (refer to footnotes of Tables 4 and 5). The bolt/nut performance of any alternate combination, when used in a structural joint, will equal or be better than the recommended combination. Numbers (1 thru 8) are the bolt item numbers given in Table 4, letters (A thru G) are the nut item numbers given in Table 5.

F. 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 plan 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 done.

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 bolt's nominal length minus its thread transition length, $L_B \text{ min} = L\text{nom} - L_T - Y \text{ max}$. For L_T and Y values, refer to page E-34.

Using the specified body length the designer can quickly check the location of shear planes in any joint. As an example —

A structural joint is comprised of 3 plies, the outer plates are each ½ in. thick and the interior plate is 1 in. Hardened flat washers will be used under both the bolt head and nut and 7/8 in. bolts will be used. The grip is 2 x 0.5 + 1.0 + 2 x 0.136 = 2.272 in. Referring to Table 7, a 7/8 x 3.5 in. bolt is the correct choice. Its specified body length is 1.72 in. The two shear planes occur at distances of 0.136 + 0.5 = 0.636 in. and 0.136 + 0.5 + 1.0 = 1.636 in. from the underside of the bolt head, regardless from which side of the joint the bolt is installed. Both shear planes occur through full body and not through the threaded length.

Another example —

Assume again a joint of 3 plies with the outer plates 5/8 in. and 5/16 in. and the interior plate 1 in. Only one washer is needed, to be placed under the turned member. Again, 7/8 in. bolts will be used. The grip is 0.312 + 1.0 +

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Table 7 Grip Ranges for High Strength Structural Bolts

Nom Bolt Dia and Thds per Inch	1/2 - 13		5/8 - 11		3/4 - 10		7/8 - 9		1 - 8		1-1/8 - 7		1-1/4 - 7		1-3/8 - 6		1-1/2 - 6	
Nom Bolt Length in.	Grip Range, in.																	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1.25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.50	0.55	0.79	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.75	0.80	1.04	0.56	0.89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.00	1.05	1.29	0.81	1.14	0.69	0.94	—	—	—	—	—	—	—	—	—	—	—	—
2.25	1.30	1.54	1.06	1.39	0.94	1.19	0.82	1.09	—	—	—	—	—	—	—	—	—	—
2.50	1.55	1.79	1.31	1.64	1.19	1.44	1.07	1.34	—	—	—	—	—	—	—	—	—	—
2.75	1.80	2.04	1.56	1.89	1.44	1.69	1.32	1.59	1.08	1.47	—	—	—	—	—	—	—	—
3.00	2.05	2.29	1.81	2.14	1.69	1.94	1.57	1.84	1.33	1.72	1.10	1.53	1.10	1.42	—	—	—	—
3.25	2.30	2.54	2.06	2.39	1.94	2.19	1.82	2.09	1.58	1.97	1.35	1.78	1.35	1.67	1.11	1.54	1.11	1.41
3.50	2.55	2.79	2.31	2.64	2.19	2.44	2.07	2.34	1.83	2.22	1.60	2.03	1.60	1.92	1.36	1.79	1.36	1.66
3.75	2.80	3.04	2.56	2.89	2.44	2.69	2.32	2.59	2.08	2.47	1.85	2.28	1.85	2.17	1.61	2.04	1.61	1.91
4.00	3.05	3.29	2.81	3.14	2.69	2.94	2.57	2.84	2.33	2.72	2.10	2.53	2.10	2.42	1.86	2.29	1.86	2.16
4.25	3.30	3.54	3.06	3.39	2.94	3.19	2.82	3.09	2.58	2.97	2.35	2.78	2.35	2.67	2.11	2.54	2.11	2.41
4.50	3.55	3.79	3.31	3.64	3.19	3.44	3.07	3.34	2.83	3.22	2.60	3.03	2.60	2.92	2.36	2.79	2.36	2.66
4.75	3.80	4.04	3.56	3.89	3.44	3.69	3.32	3.59	3.08	3.47	2.85	3.28	2.85	3.17	2.61	3.04	2.61	2.91
5.00	4.05	4.29	3.81	4.14	3.69	3.94	3.57	3.84	3.33	3.72	3.10	3.53	3.10	3.42	2.86	3.29	2.86	3.16
5.25	4.30	4.54	4.06	4.39	3.94	4.19	3.82	4.09	3.58	3.97	3.35	3.78	3.35	3.67	3.11	3.54	3.11	3.41
5.50	4.55	4.79	4.31	4.64	4.19	4.44	4.07	4.34	3.83	4.22	3.60	4.03	3.60	3.92	3.36	3.79	3.36	3.66
5.75	4.80	5.04	4.56	4.89	4.44	4.69	4.32	4.59	4.08	4.47	3.85	4.28	3.85	4.17	3.61	4.04	3.61	3.91
6.00	5.05	5.29	4.81	5.14	4.69	4.94	4.57	4.84	4.33	4.72	4.10	4.53	4.10	4.42	3.86	4.29	3.86	4.16
6.25	—	—	—	—	4.94	5.19	4.82	5.03	4.58	4.91	4.35	4.78	4.35	4.67	4.11	4.54	4.11	4.41
6.50	—	—	—	—	5.19	5.44	5.07	5.28	4.83	5.16	4.60	5.03	4.60	4.92	4.36	4.79	4.36	4.66
6.75	—	—	—	—	5.44	5.69	5.32	5.53	5.08	5.41	4.85	5.28	4.85	5.17	4.61	5.04	4.61	4.91
7.00	—	—	—	—	5.69	5.94	5.57	5.78	5.33	5.66	5.10	5.53	5.10	5.42	4.86	5.29	4.86	5.16
7.25	—	—	—	—	5.94	6.19	5.82	6.03	5.58	5.91	5.35	5.78	5.35	5.67	5.11	5.54	5.11	5.41
7.50	—	—	—	—	6.19	6.44	6.07	6.28	5.83	6.16	5.60	6.03	5.60	5.92	5.36	5.79	5.36	5.66
7.75	—	—	—	—	6.44	6.69	6.32	6.53	6.08	6.41	5.85	6.28	5.85	6.17	5.61	6.04	5.61	5.91
8.00	—	—	—	—	6.69	6.94	6.57	6.78	6.33	6.66	6.10	6.53	6.10	6.42	5.86	6.29	5.86	6.16

0.625 + 0.136 = 2.073 in. Table 7 recommends a 7/8 x 3.25 in. bolt be selected. Its body length is 1.47 in. If the bolt is installed from the 5/8 in. plate side, the shear planes will occur 0.625 and 1.625 in. from the head. One shear plane will be through the full body, the other through the threaded section, regardless of washer location. If, however, the bolt is installed from the 5/16 in. plate side, the shear planes occur 0.312 and 1.312 in. from the underside of the bolt head. Both are through full body. If, for tightening reasons, the washer is placed under the bolt head rather than the nut, the shear planes move to 0.448 and 1.448 in. from the underside of the head. Both are still through full body.

This suggests that, whenever possible, if the outer plates in a connection are of unequal thickness, it may enhance allowable bolt shear stresses if the bolt is installed from the thinner plate side.

G. Bolt Length/Grip Range.

Table 4 presents the grip ranges which can be accommodated by the various diameter/length combinations of high strength structural bolts. Grip is defined as the total thickness of material, including washers, to be connected by the bolt. When washers are used the 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 and what is the maximum?

Minimum Grip.

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, see page E-34). The grip gaging length is the maximum distance from the underhead bearing surface of the bolt to the face of a non-countersunk or non-counterbored 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.

When tightening high strength structural bolts using the turn-of-nut method most bolt diameter/length combinations require 1/2 to 2/3 of nut rotation following bringing the joint to "snug tight." Longer bolts sometimes require one full turn.

Because nuts are countersunk on their bearing faces, the depth of countersink can be assumed as being available for nut tightening purposes. Countersink depths approximate 1/3 thread pitch. Therefore, it is reasonable to assume the minimum grip for a bolt is its grip gaging length plus 0.67 times the length of one of its threads.

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.

Minimum grips for high strength structural bolts are computed as follows:

$$G_{min} = L_G + 0.67\,P$$

where

- G = grip
- L_G = grip gaging length, max
- P = thread pitch

Example:

For a 7/8 – 9 x 4 in. bolt
L_G = 2.500 in.
P = 0.111 in.

and $G_{min} = 2.500 + 0.67 \times 0.111 = 2.57$ in.

In this example, in the extreme conditions, connecting a grip of 2.57 in. would result in a bolt stick through beyond the face of the nut ranging from 0.355 to 0.597 in.

Maximum Grip.

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.

Maximum grips for high strength structural bolts are computed as follows:

$$G_{max} = L - L_{tol} - H - 2\,W_{tol}$$

where

- G = grip
- L = bolt length, nominal
- L_{tol} = bolt length tolerance, minus (see page E-35)
- H = nut thickness, max (see Table 2)
- W_{tol} = washer thickness tolerance (see Table 3) (max thickness minus min thickness) (Note: flat washer thickness tolerances are used.)

COMMENTARY ON HIGH STRENGTH STRUCTURAL BOLTING

Example:

For a 7/8 – 9 x 4 in. bolt

$L = 4.000$
$L_{tol} = 0.19$ in.
$H_{max} = 0.885$ in.
$W_{tol} = 2 \times 0.041 = 0.082$ in.

$G_{max} = 4.000 - 0.19 - 0.885 - 0.082 = 2.84$ in.

If a grip of 2.84 in., including 2 washers, is connected with a 7/8 x 4 in. bolt of its permitted minimum length and a nut of maximum thickness and the washers which are supplied are at their permitted maximum thickness, the end of the bolt will be exactly flush with the nut face. For all other conditions there will be a positive stick through of the bolt beyond the nut face, ranging up to a maximum of 0.245 in.

The grip ranges given in Table 7 were established using these formulas. There are two modest exceptions. For all lengths of 1/2 in. bolts and lengths of 3/4 in. longer than 6 in. it was necessary to slightly increase the maximum grip to assure all grips were accommodated within the pattern of 1/4 in. length increment bolts. This was reasonable because the conditions controlling maximum grips are less critical than those for minimum grips.

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.

For a fuller discussion of tightening beyond yield and the various bolt tightening methods, refer to the article "Design of Bolted Joints — An Introduction," page M-52.