U.S. Department of Transportation
Federal Highway Administration

DEMONSTRATION PROJECT NO. 88
HIGH-STRENGTH BOLTS FOR BRIDGES

High Strength Bolts for Bridges

PB2001-103932

Addendum

High Strength Bolts for Bridges

Report No. FHWA-SA-91-031

(date of Addendum: April 14, 1994)

This publication was prepared in accordance with the standards and specifications in effect in early 1991. These items include ASTM, ANSI and AASHTO specifications. Since that time, there have been several changes to these documents. This addendum incorporates a brief summary of the changes made to date when it affects slides or text.

ASTM fastener specifications are frequently updated, sometimes several times in one year. One is encouraged to secure updated copies of all applicable ASTM specifications.

ANSI B18.2.1-1981 and ANSI B18.2.2-1987 are current as of this Addendum.

AASHTO Standard Specifications for Highway Bridges are updated annually, with supplements being published each Spring. At the time of preparation of the Demonstration Project 88 slides and the text, AASHTO Division II placed the material on Steel Structures in Section 10. This section has subsequently been renumbered to Section 11. It should also be noted that a substantial percentage of the provisions of the FHWA Memorandum, November, 1989, have been or will soon be incorporated into the AASHTO Specifications.

Two versions of the Research Council on Structural Connections Specification for Structural Joints Using ASTM A325 or A490 Bolts currently exist. The 1985 version is for use in Allowable Stress Design, the 1988 for Load and Resistance Factor Design. Some installation and inspection procedures were revised with the publication of the 1988 version, and a thorough comparison should be made of the two specifications.

The following changes should be made to the slides and accompanying text:

2- 1 Fourth sentence: Change "The existing specifications do not" to "The previous specifications did not". New AASHTO provisions now call for rotational-capacity testing of both A325 and A490 bolts.

2-10 Check current ASTM specifications for overtapping provisions.

2-13 **Matching Nuts**

A325/M164	A563/M291	A194/M292
Type 1 & 2	C,C3,D,DH,DH3	2,2H
Type 1 Galv.	DH	2H

3- 8 A325 Type 2 bolts were withdrawn from use in November, 1991.

3-10 A325 maximum hardness has been revised to 34 HRC, down from 35 HRC.
3-22
3-23
3-24

3-26 Alexander's model:

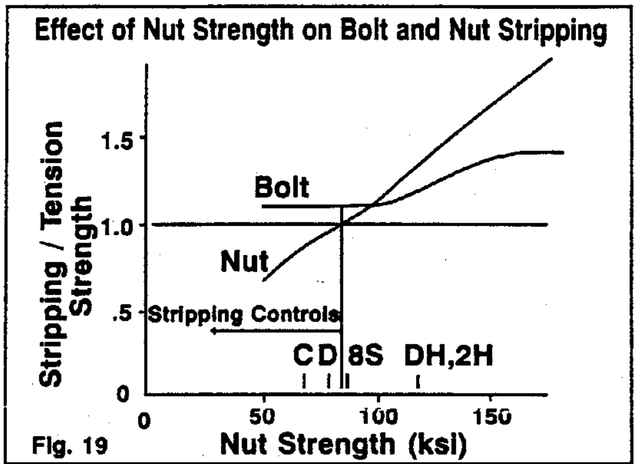


Fig. 19

3-30 Overtapping provisions have been substantially revised in A563. See current specifications. A563 provisions still do not meet FHWA requirements.

3-52 The top solid line is for "As Received and Lubricated Cases". The bottom solid line is for "Clean". The equation for the center dashed line is T = 16.7 P D.

3-53 AASHTO reference in Division II is now Article 11.5.6.

4-47 IFI-122 is provided as a separate handout, not included in the bound text.

4-58 A325 Type 2 bolts were withdrawn from use in November, 1991.

6-15 Change slide: "P = measured bolt tension (lbs.)". Also, delete the last sentence of the text.

6-20 Change slide: "P = "turn test tension" from Table D4.1g.

7- 2 AASHTO Bridge code is now 15th edition, with Interim
7- 4 Specifications issued annually.

7- 8 Change slide: "whichever is less" to "whichever is greater".

7-13 Delete from text: "slip-critical".

7-14 Change text: "Table 10.17A" to "Table 11.5A".

7-15 Change slide and text: "Table 10.17A" to "Table 11.5A".

7-18 Change slide: "f_y" TO "F_y".

8- 1 "Alternate Design Bolts" and "Lock-Pin and Collar Fasteners" are also recognized by AASHTO.

8- 3 Change text: "Table 10.17A" to "Table 11.5A".

8- 6 Change slide and text: "Table 10.17B" to "Table 11.5B".

9- 5 For bridge applications, the typical gap is 0.005 inches.

10- 2 Change text: "Table 10.17A" to "Table 11.5A".

10- 8 Change slide and text: "Table 10.17B" to "Table 11.5B".

11- 1 Change text: "Table 10.17A" to "Table 11.5A", and change "Article 10.3.1.8.9" to "Article 11.3.2.6".

11- 2 Change slide and text: "10.3.1.8.9" to "11.3.2.6".

11- 3 Change text and slide: "Table 10.17A" to "Table 11.5A".
12- 6 Change text: "Article 10.3.1.8.9" to "Article 11.3.2.6".

12- 8 These provisions are drawn from the RCSC Bolt Specification. AASHTO provides for sampling 3 bolts, not five. Change text: "Table 10.17A" to "Table 11.5A". Change text: "Table 10.17B" to "Table 11.5B".

12-10 These provisions are drawn from the RCSC Bolt Specification. AASHTO provides for sampling 3 bolts and using the average of the three bolts.

12-11 The RCSC provisions cited in the text call for inspection wrench inspection only for "connections in question". AASHTO provisions require inspection wrench inspection of all high-strength bolted connections except those using alternate design fasteners or direct tension indicators.

The following changes and corrections should be made to the appendices that follow the slides and commentary in the publication:

Appendix A2, A3, A4 and A5

Change all references: "Table 10.17A" to "Table 11.5A"
Change all references: "Table 10.17B" to "Table 11.5B"

Appendix A1

In Procedure Section 3, change "snug tension" to "initial tension".

Appendix A2

Add the following sentence to Section 2.3: "Install sufficient spacers and/or washers so that at least three (3) but no more than five (5) full threads are exposed between the nut face and the underside of the bolt head."

Correct the values at the top of the second page for Table 10.17A.

Table 11.5A - Required Fastener Tension (kips)									
Bolt Diam. (inches)	**1/2**	**5/8**	**3/4**	**7/8**	**1**	**1-1/8**	**1-1/4**	**1-3/8**	**1-1/2**
M164 (A325)	12	19	28	39	51	56	71	85	103
M253 (A490)	15	24	35	49	64	80	102	121	148

Appendix A6

Replaced in its entirety. See attachment.

APPENDIX A6
PROCEDURE FOR VERIFICATION AND INSTALLATION OF HIGH STRENGTH BOLTS WITH DIRECT TENSION INDICATORS (DTI's)
(Part of Report No. FHWA-SA-91-031 May 1991, revised April 1992)

I. Verification of DTI Performance

Verification of DTI performance is required prior to installation of bolts in the work. In bridge work the manufacturers are typically specifying smaller gaps in the spaces between the protrusions on the washer than normally used in other construction and the gap specified for testing in the product specification ASTM F959. The basic principle used in this verification test is to make sure that there is a DTI gap at 1.05 times the required bolt installation tension greater than what is to be used as a job installation inspection requirement. The verification test method involves determining the maximum number of spaces at which a 0.005 in. tapered feeler gage is refused, does not fit into the space, at a load equal to 1.05 times the required bolt installation tension. This maximum number of spaces is one less than the job installation inspection requirement. The installation inspection requirement is often referred to as the project gap. In addition, as part of the verification test, the DTI's shall be further compressed to a level such that the inspection feeler gage is refused at all spaces between the protrusions of the washer and a visible gap still remaining in at least one space. The bolt load at this smallest gap should not cause excessive permanent inelastic deformation of the fastener. The degree of inelastic deformation is judged by removing the fastener from the test apparatus and turning the nut by hand the full length of the threads on the bolt after the test. If the nut can be turned the full thread length, the DTI smallest gap load requirement is satisfied. Alternatively the bolt load at this smallest gap should not exceed 95% of the load recorded in step 6 of the rotational capacity test for long bolts. The installation verification test shall be performed three times for each fastener rotational capacity lot on the job with the corresponding diameter of DTI to be used. If the same RC lot is to be installed with the DTI in two different positions with respect to the turned element, three tests are required for each position of the DTI. Bolts from RC lots too short to fit in the tension measuring device shall be tested by tightening in a steel plate to the minimum gap in step 6 and checked in accordance with step 7, except that the 95% alternative cannot be used. The DTI used with the short bolts should be checked in accordance with steps 1 through 5 using a longer bolt in the tension measuring device.

<u>Equipment Required:</u>

1. Calibrated bolt tension measuring device with a special flat insert in place of normal bolt head holding insert. Special insert required to allow access to measure DTI gap.

2. Tapered leaf thickness (feeler) gage 0.005 inch. Same gage as to be used to inspect the bolts after installation.

3. Bolts, nuts, and standard washers to be used in the work with the DTI's.

4. Impact and manual wrench to tighten bolts. Equipment should be the same as to be used in the work.

<u>Verification Test Procedure:</u> (Test three sets for each RC lot and position of DTI)

1. Install bolt, nut, DTI and standard washer (if used) into bolt tension measuring device. Assembly should match that to be used in the work.

2. Use another wrench on the bolt head to prevent rotation of the head against the DTI if the DTI is to be used under the unturned element.

3. Tighten bolt to tensions listed below (1.05 times the required pretension of the bolt). Use another wrench on the bolt head to prevent rotation of the head against the DTI if the DTI is to be used under the unturned element. If an impact wrench is used, tighten to a load slightly below the required load and use a manual wrench to attain the required tension. The load indicating needle of the bolt calibrator cannot be read accurately when an impact wrench is used.

Bolt Tension (kips)									
Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
M164 (A325)	12	20	29	41	54	59	75	89	108

4. Determine and record the number of spaces between the protrusion on the DTI that a 0.005 in. thickness gage is refused. The total number of spaces in the various sizes and grade of DTI's is shown below.

Number of Spaces									
Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
M164 (A325)	4	4	5	5	6	6	7	7	8
M253 (A490)	na	na	6	6	7	7	8	8	na

5. The number of spaces which the 0.005 in. gage is refused should not exceed the number given in the table below. If the number of spaces exceeds the number in the table, the DTI fails the verification test.

Verification Criteria*					
Number of spaces in washer	4	5	6	7	8
Maximum number of spaces gage is refused	1	2	2	3	3

*If the test is a coated DTI under the turned element, the maximum number of spaces the gage is refused is the number of spaces on the washer minus one.

6. The bolt should be further tightened to the smallest gap to be allowed in the work. Normally, this smallest gap condition is achieved when the gaps at all the spaces are less than 0.005 in. (or a gap size as approved by the engineer) and not all gaps completely closed. When such a condition is achieved the 0.005 in. gage is refused at all spaces but a visible gap exists in at least one space. Note the load in the bolt at this smallest gap. The bolts in this installation verification test and in the actual installation should not be tightened to a no visible gap condition, i.e. a condition when all the gaps are completely closed. The load in the bolt becomes indeterminant when no gap exists. It is possible to cause bolt failure by tightening beyond complete crushing of the washer.

7. Remove the bolt from the calibrator and turn the nut on the threads of the bolt by hand. The nut should be able to be turned on the complete length of the threads, excluding the thread runout. Alternatively, if the nut is unable to go the full thread length, but the load at the minimum DTI gap (measured in step 6 above) is less than 95% of the maximum load achieved in step 6 Appendix 1 of the rotational capacity test, the assembly, including the DTI, is deemed to have passed this test. If the nut cannot be run the full thread length, and if the load at the smallest gap condition is greater than 95% of the maximum strength of the bolts from the rotational-capacity test, the load required for the smallest gap in step 6 is too large. If approved by the engineer, the test could be repeated with a larger minimum gap, for example one space that will accept a 0.005 in. feeler gage, or the DTI's could be replaced.

Short Bolts:

Bolts from RC lots too short to fit in the tension measuring device shall be tested by tightening to the minimum gap in step 6 and checked in accordance with step 7. The 95% alternative cannot be used since short bolts are not tested in the tension measuring device for rotational capacity. The DTI used with the short bolt should be checked in accordance with steps 1 through 5 using a longer bolt in the tension measuring device.

II. Installation:

1. The use of a DTI under the unturned bolt head requires that the element bearing against the DTI not turn. Two men are required: One to operate the wrench, and the other to prevent turning of the element with the DTI and to monitor the gap. If the DTI is used under the turned element, an additional hardened washer must be used between the turning element and the protrusion on the DTI.

2. Snug the connection to compact the joint. The DTI should be inspected after snugging and the gaps checked. If the number of spaces in which the 0.005 in. gage is refused exceeds the value in the table shown above in step 5 of the verification test, the bolt must be removed and another DTI installed. The bolt should be resnugged.

3. Tighten the bolts systematically to the inspection gap. The number of spaces in which the 0.005 in. gage is refused should be equal or greater than the number shown in the table below. Tightening beyond the smallest gap established above in steps 6 and 7 is not allowed. Bolts which have a DTI with a smaller gap or no gap shall be replaced and the bolts tightened with a new DTI.

Inspection Criteria*					
Number of spaces in washer	4	5	6	7	8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fastener Worksheet

Fastener	Tension	Torque
Black - as received (—lubed—; lubricated nut)	spec. → 28k	210 ft/lb.
Black - rusted	19k	220
Black - dry	31k (should be lower)	210
Black - relubed	17k	210
Galv. - as received (—lubed—; lubed nut.)	28k	140 ft/lb.
Galv. - no lube on nut	12k	140 ft/lb.
Galv. - lube added	27k	140

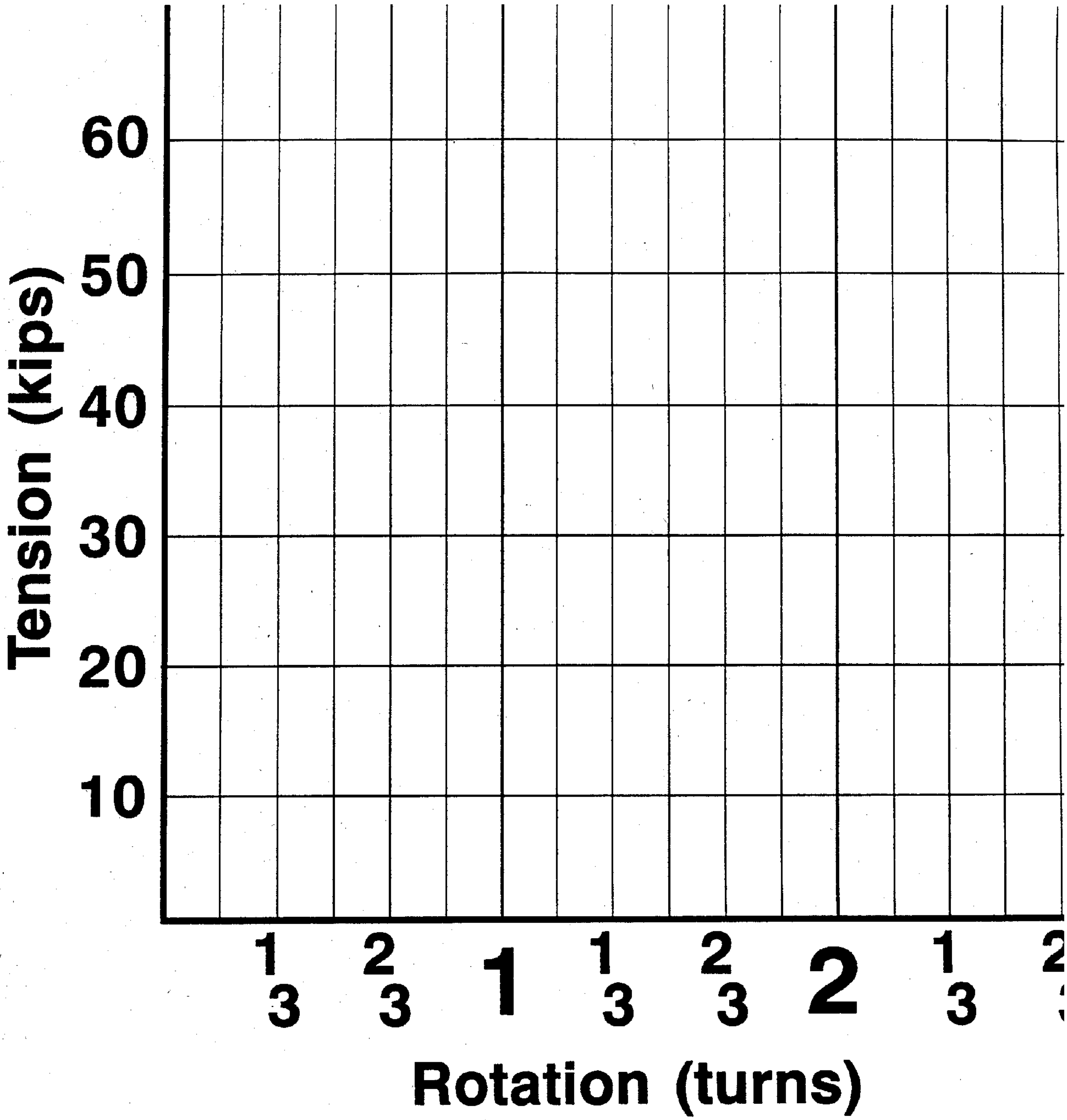
do not use dry bolts

lose top off

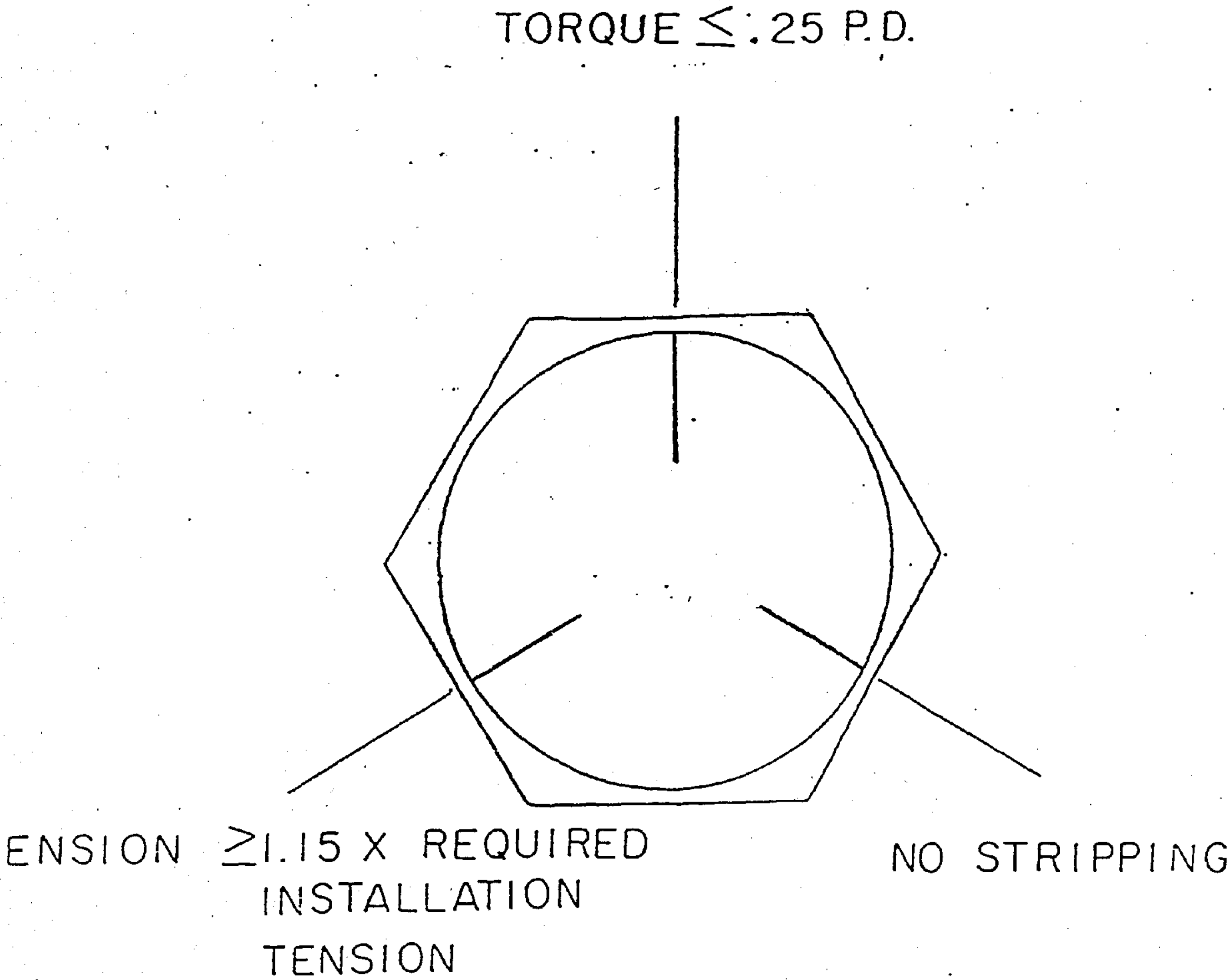
Notes: Wax works better than oil for a lubricant

Torque is not a good indicator

Tension - Elongation



ROTATIONAL CAPACITY TEST REQUIREMENTS



Rotatioal-Capacity Test Worksheet
Long Bolt Procedure

Grade = A325/M164   Bolt Diameter = 3/4

Bolt Length = ________
Measured Tension = _____
Measured Torque = ______

Maximum Permitted Torque

$T = 0.25\ P\ D$

P = tension(pounds)

D = bolt diameter(feet)

$= 0.25[(3/4)/12]P = 0.0156P$

Maximum Torque = ______

Bolt Length	Both faces normal to bolt axis
L = 4D	2/3 turn
4D < L = 8D	1 turn
8D < L	1-1/3 turn

Measured Tension = _______ (min.-32k)

Verify condition of threads - ok____

Rotatioal-Capacity Test Worksheet
Short Bolt Procedure

Grade = A325/M164   Bolt Diameter = 3/4

Bolt Length = ________

Bolt Length	Both faces normal to bolt axis
L = 4D	1/3 turn

Measured Torque = ________

Maximum Permitted Torque = 500ft-lb

Bolt Length	Both faces normal to bolt axis
L = 4D	2/3 turns

Verify condition of threads

ok_____

Rotatioal-Capacity Test Worksheet
Long Bolt Procedure

Grade = A325/M164 Bolt Diameter = 7/8

Bolt Length = 2 3/4

Measured Tension = 39 k

Measured Torque = 260 ft/lb

Maximum Permitted Torque

$$T = 0.25\ P\ D$$

P = tension(pounds)

D = bolt diameter(feet)

$$= 0.25[(7/8)/12]P = 0.0182P$$

Maximum Torque = 400 ft/lb

Bolt Length	Both faces normal to bolt axis
L = 4D	2/3 turn
4D < L = 8D	1 turn
8D < L	1-1/3 turn

Measured Tension = 55 k (min.-45k)

Verify condition of threads - ok____

Rotatioal-Capacity Test Worksheet
Short Bolt Procedure

Grade = A325/M164   Bolt Diameter = 7/8

Bolt Length = _______

Bolt Length	Both faces normal to bolt axis
L = 4D	1/3 turn

Measured Torque = _______

Maximum Permitted Torque = 820ft-lb

Bolt Length	Both faces normal to bolt axis
L = 4D	2/3 turns

Verify condition of threads

ok_____

ROTATIONAL CAPACITY TEST / MAXIMUM TORQUE			
¾ INCH BOLT		⅞ INCH BOLT	
TENSION (KIPS)	TORQUE (FT-LBS)	TENSION (KIPS)	TORQUE (FT-LBS)
28	437	39	711
29	453	40	729
30	469	41	747
31	484	42	766
32	500	43	784
33	516	44	802
34	531	45	820
35	547	46	839
36	562	47	857
37	578	48	875
38	594	49	893
39	609	50	911
40	625	51	930
41	641	52	948
42	656	53	966
43	672	54	984
44	688	55	1003
45	703	56	1021

The following is the data that should be included in the rotational capacity test certification. The information may be presented in any form the certifier chooses.

ROTATIONAL CAPACITY TEST CERTIFICATION

DATE OF TEST________________ TESTING FIRM____________________

LOCATION OF TEST____________ TESTER NAME_____________________

	BOLT	NUT	WASHER
MANUFACTURER	________	________	________
LOCATION OF MANUF	________	________	________
LOT NO.	________	________	________
SPEC.(ASTM)	________	________	________
GRADE(NUT)	________	________	________

BOLT SIZE : DIA x LENGTH____________________

TEST:(FHWA)______ (ASTM)_____ REQUIRED ROTATION______________

Test Notes:

1. Torque/Tension comparison between minimum tension (proof load) and full required rotation in test.
2. Tension at required turn>1.15 proof load.
3. Stripping (must turn with fingers after test) - no stripping passes.
4. Two samples are required to be tested.

SAMPLE I:

1. MEASURED TORQ_____TENSION______MAX.ALLOW.TORQUE @ T=.25PD_____
2. MEASURED TENSION @ REQ. TURN_________ MIN. REQ. TENSION______
3. STRIPPING YES_____ NO_____

SAMPLE II:

1. MEASURED TORQ_____TENSION______MAX.ALLOW.TORQUE @ T=.25PD_____
2. MEASURED TENSION @ REQ. TURN_________ MIN. REQ. TENSION______
3. STRIPPING YES_____ NO_____

R/C TEST LOT NO.__________________ TEST PASSED_________

SIGNATURE OF TESTER________________

NOTARY PUBLIC:
(Optional)

Installation Verification Tests

Installation Method	Achieved Tension
Turn of Nut	
Calibrated Wrench	
Direct Tension Indicator	
Twist-Off Bolt	
Lock Pin & Collar	

Minimum Required Tension for 3/4" A325 = 28 k

Minimum Achieved Tension for 3/4" A325 = 29 k

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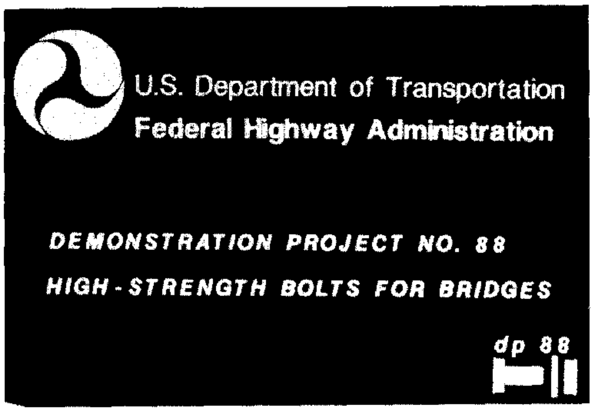
Session 1
Introduction, Objectives and Problems Encountered



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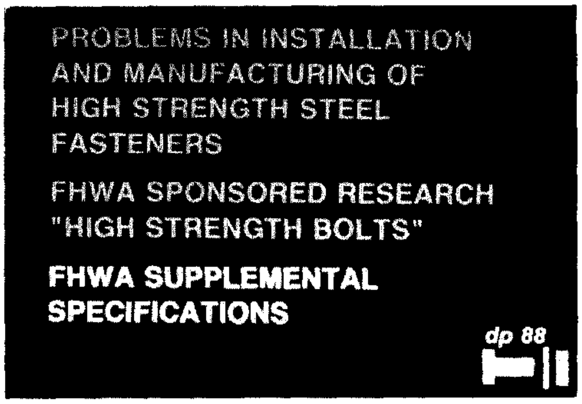
INTRODUCTION



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In the mid 1980's a number of problems developed during the installation of high-strength bolts in bridge structures. Because improperly manufactured and installed and poorly inspected fasteners can precipitate structural failures, FHWA sponsored a research project at the University of Texas to determine various problems concerning manufacturing and installation of high-strength bolts for bridges, and to make recommendations toward resolving them. Upon completion of this work, FHWA issued the "Supplemental Contract Specifications for projects with AASHTO M164 (A325) H. S. Bolts" in 1989 in order to provide uniform manufacturing and installation requirements. This specification was developed as a supplement to the AASHTO Materials Specifications.

FASTENERS

Discussion of fasteners will be limited to high-strength bolts, nuts and washers for bridges.

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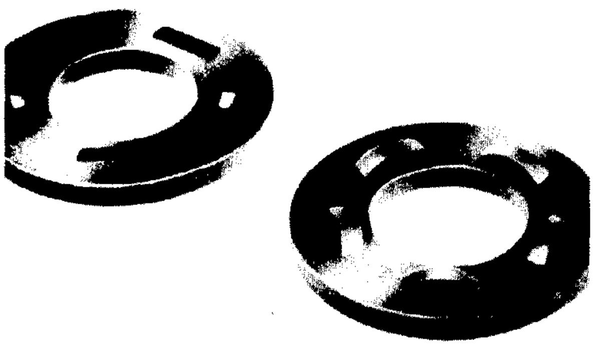

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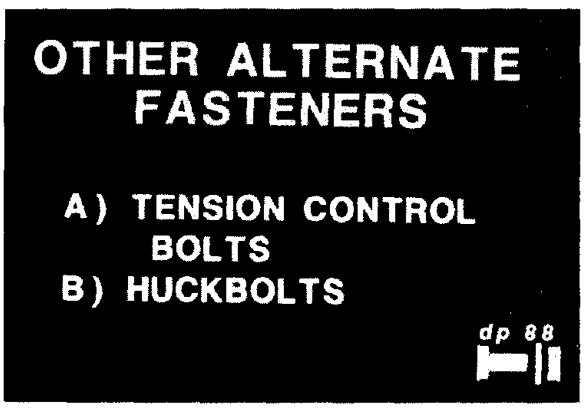

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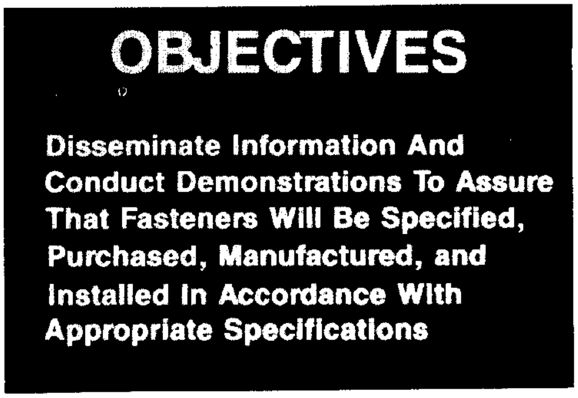

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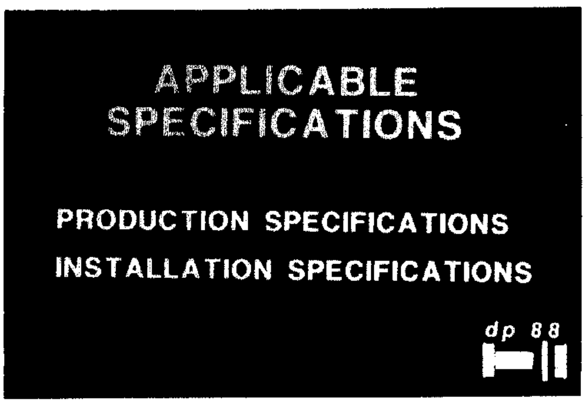
OBJECTIVES

The objectives of this project are to disseminate relevant information and demonstrate various techniques and methods to assure that all bolts will be specified, purchased, manufactured and installed in accordance with the appropriate specification requirements. Special emphasis will be given toward explaining the rationale behind the new specifications and demonstrating appropriate tests and methods so they will be better understood.



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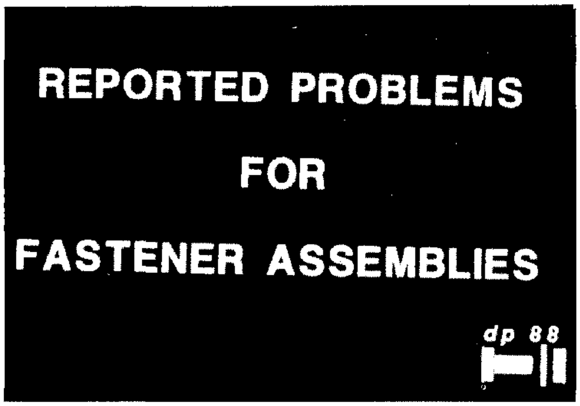
REPORTED PROBLEMS FOR FASTENER ASSEMBLIES



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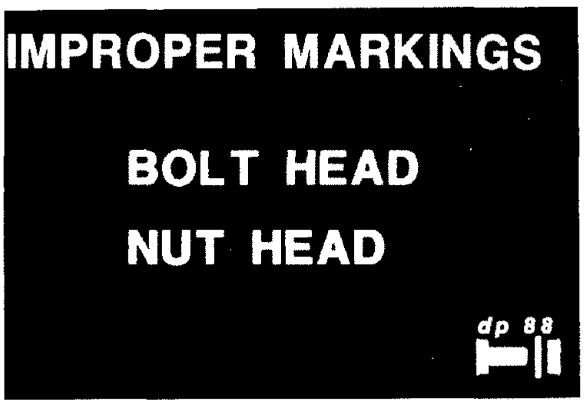

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<u>REPORTED PROBLEMS FOR FASTENER ASSEMBLIES</u> (Cont'd.)

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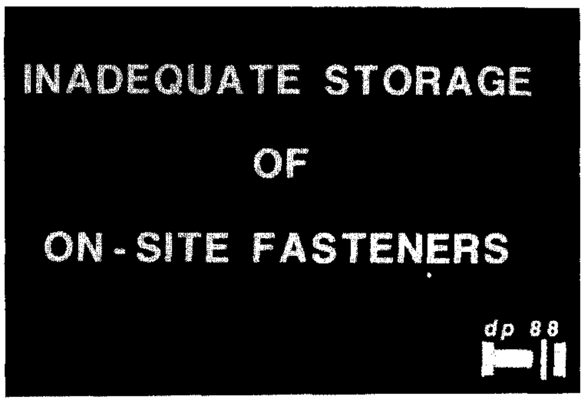

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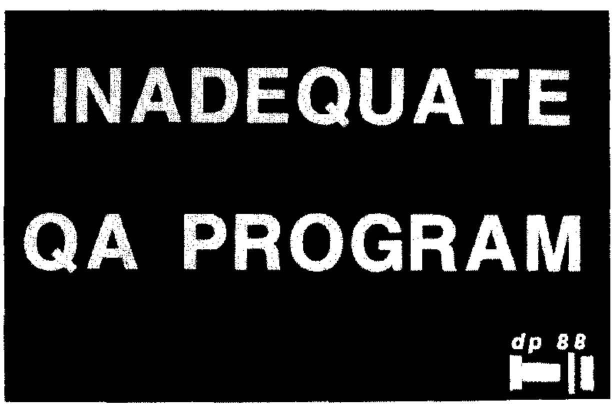

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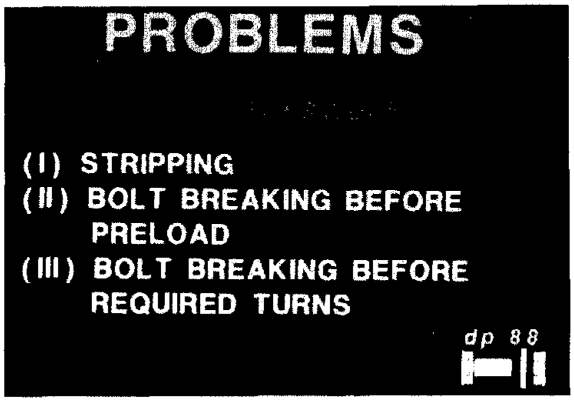
REPORTED PROBLEMS FOR FASTENER ASSEMBLIES (Cont'd.)



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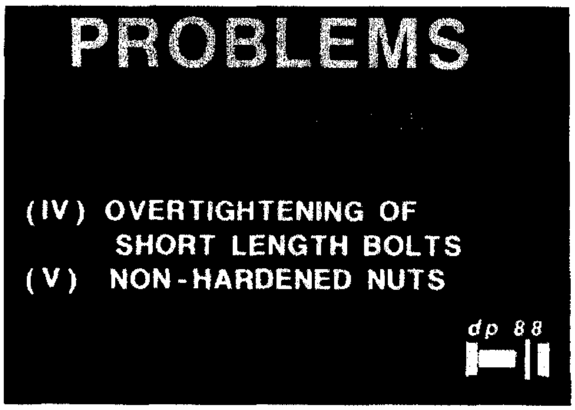

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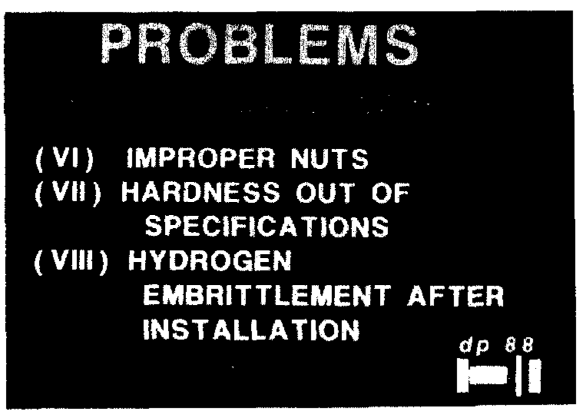

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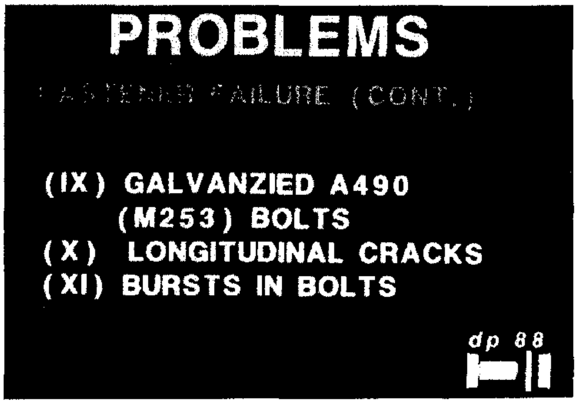
REPORTED PROBLEMS FOR FASTENER ASSEMBLIES (Cont'd.)



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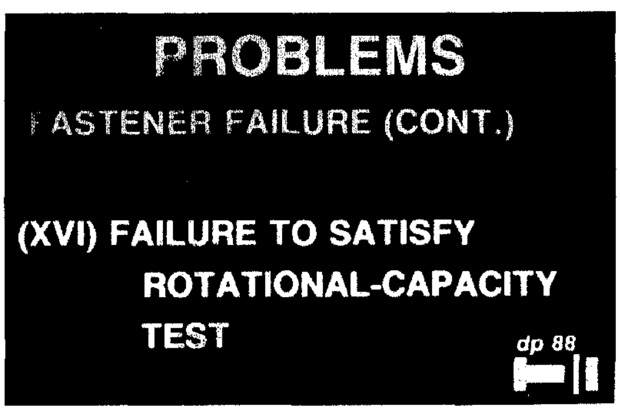

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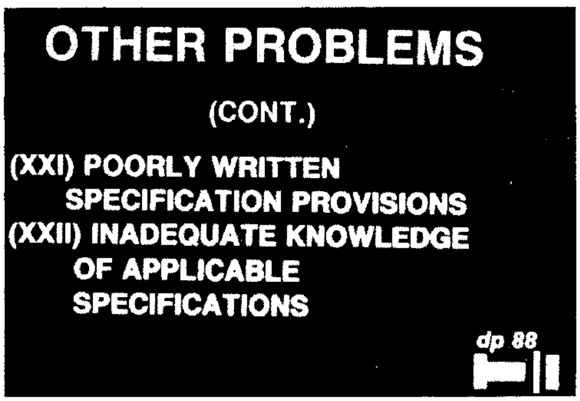
<u>REPORTED PROBLEMS FOR FASTENER ASSEMBLIES</u> (Cont'd.)



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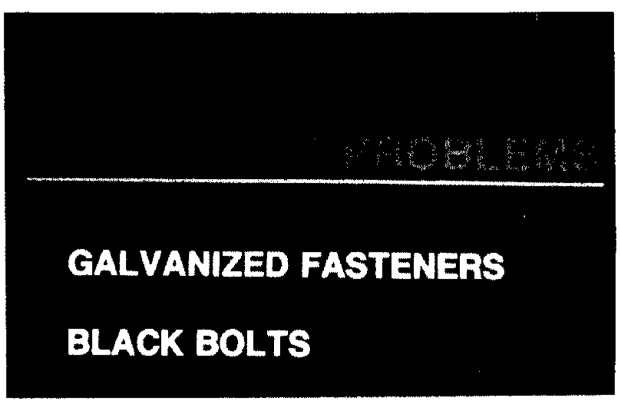

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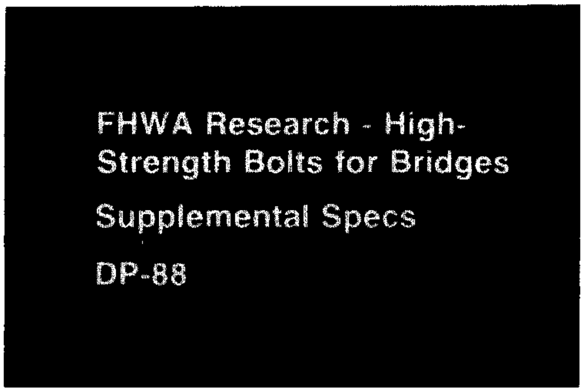
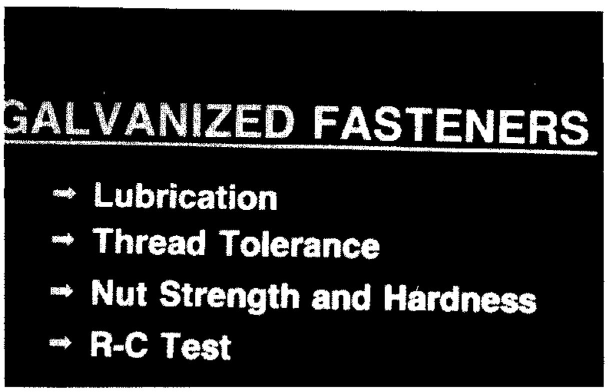
These issues and problems were significant enough to require research, implementation of recommendations, and development of FHWA Supplemental Specifications for High Strength Bolts and this demonstration project DP-88.



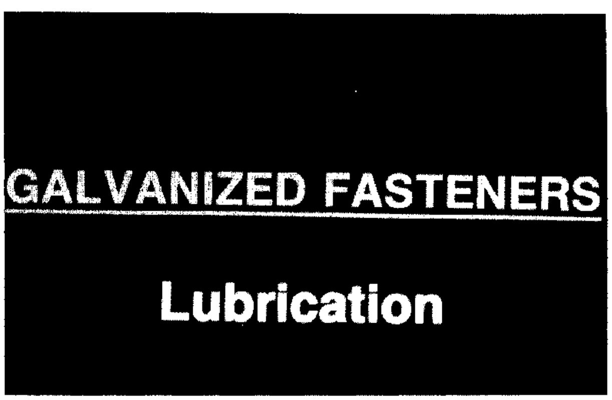
1 - 24

The FHWA sponsored research was in response to field problems with the installation of galvanized bolts in bridges. Both A325 and A490 bolts were included in the study to provide a comparision of the behavior of coated (galvanized) bolts with black bolts. This was done based on previous laboratory and field experience with installation problems of black bolts.



1 - 25

When bridge owners began using galvanized fasteners to help solve painting problems, and with the advent and use of mechanically galvanized fasteners to provide uniform, smooth surfaces, several problems surfaced primarily during installation of these bolts.



1 - 26

Lubrication has always been required for galvanized nuts. When a nut is tightened, resistance is encountered and a portion of the expended energy is used to overcome the friction at the bolt/nut thread interface and the friction between the nut, washer, and gripped material. For example, in one set of tests, the difference in torque required for a lubricated assembly and an as-received bolt to reach 39 kips was dramatic. The as-received assmbly required over 1400 ft-lbs while the lubricated assembly required less than 400 ft-lbs. It is just as important to lubricate the nut face as it is to lubricate the threads. This is accomplished by lubricating the entire nut. Lubrication has a significant effect on the bolt calibration curves. This will be discussed in detail later.

- Nuts Not Lubricated
- Lubricant Washed Away
- Lubricant Not Effective
- Lubricant Not Visible

1 - 27

Problems related to lubrication include:

- a - Lubricant may not have been applied
- b - Lubricant is washed away
- c - Lubricant may not have been effective
- d - Lubricant may not be visible.

The end result is that unless a fastener is effectively lubricated, the nut will gall and seize on the bolt and it will be impossible to install the fastener properly.

GALVANIZED FASTENERS

Thread Tolerance

1 - 28

Stripping in a fastener assembly is primarily a function of the shear area of the threads and the strength of the bolt and nut. The increase in the thread size of the bolt due to galvanizing does not increase its stripping strength. The only effect of soft zinc on the threads is the increase in friction on the threads by its tendency to gall.

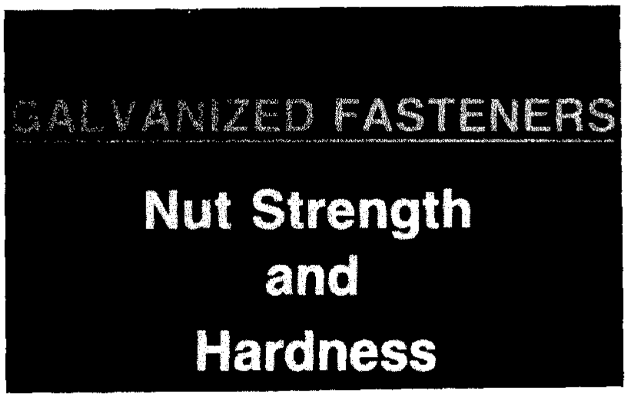
Nuts are tapped oversize to account for the thickness of the zinc coating. Excessive overtapping causes lesser thread engagement, leading to thread stripping of the nut or bolt. Previous ASTM Specifications and AASHTO Materials Specifications were incorrect, which caused the problem.

GALVANIZED FASTENERS

Rotational-Capacity Test
ASTM Requirement

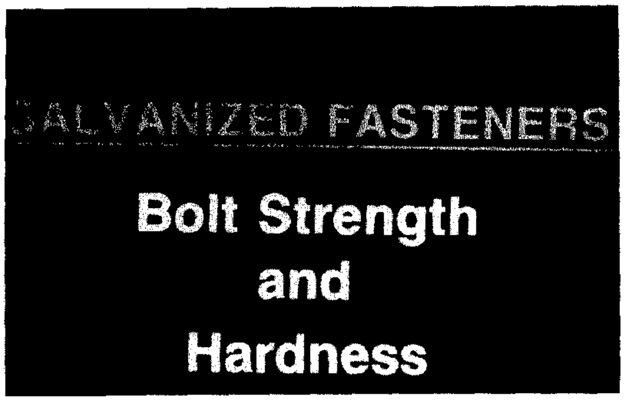
1 - 29

The ASTM specifications, for a number of years, required a rotational-capacity test. The test was not well understood and was not always performed. Had the test been performed, both the lubrication issue and the oversize tapping issue would have been somewhat resolved.



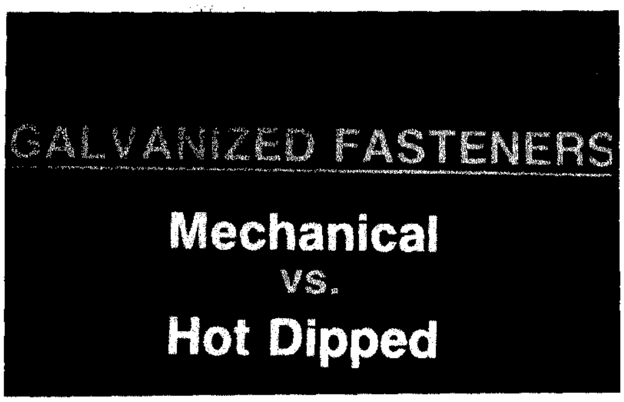
1 - 30

The strength of the nut directly affects its stripping resistance. Both hardened and nonhardened nuts were allowed in previous specifications. Nonhardened nuts do not normally have the same strength as heat treated hardened nuts, and have resulted in stripping failures. Higher-strength heat treated nuts are required for A490 bolts. Galvanized A325 fasteners also require heat treated nuts to compensate for the loss of thread shear area from overtapping.



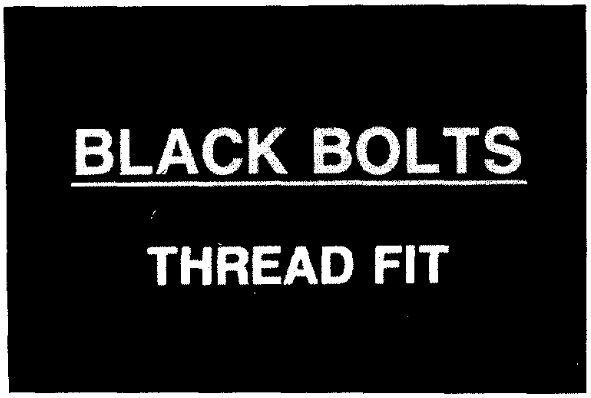
1 - 31

Current ASTM and AASHTO Materials Specifications allow A325 (M164) bolt hardness up-to 35 Rc. Bolts with hardness values greater than 33 Rc have potential for delayed cracking in service or brittle failure under applied tension loading.



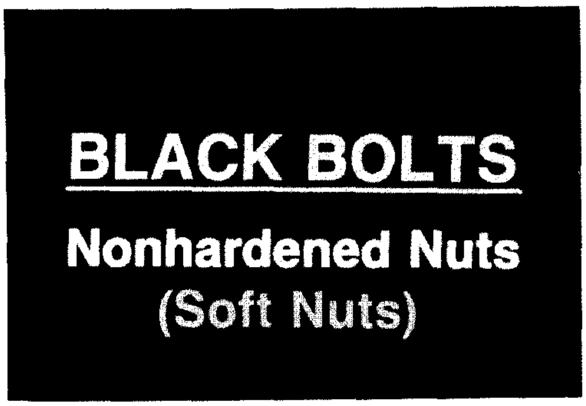
1 - 32

Uniformity of coating for mechanically galvanized fasteners allows a somewhat smaller overtap, with subsequent reduction of stripping problems.



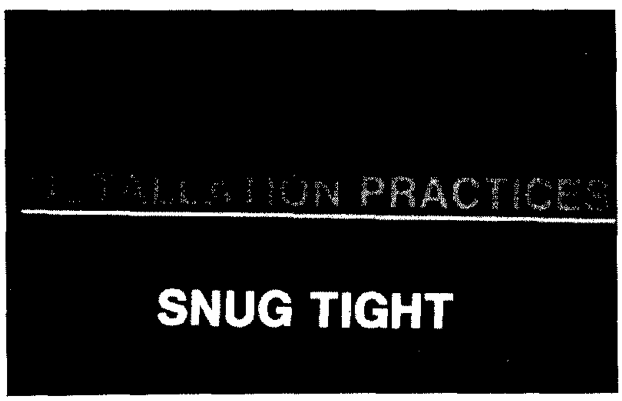
1 - 33

Nuts manufactured oversize for galvanized assemblies have, at times, been improperly used on black bolts. The oversize caused stripping failures due to a poor thread fit.



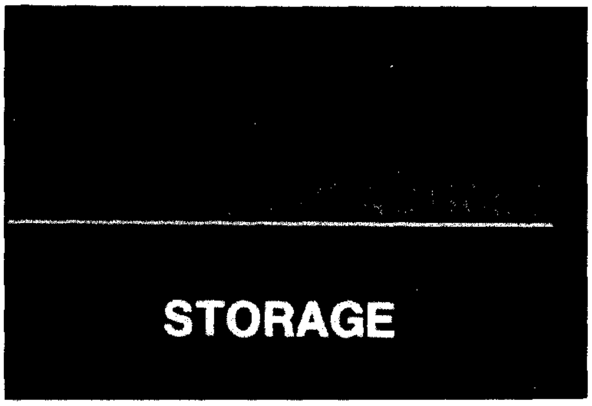
1 - 34

Both ASTM and AASHTO Materials Specifications currently allow nonhardened nuts for black assemblies. Under the permissible range of hardness, according to these specifications, nonhardened nuts can be manufactured from hardness values as low as 78 HRB to RC38. Nonhardened (softer) nuts with hardness values less than 89 HRB have a potential for stripping failure. This type of failure has been observed. Recent research work at the University of Texas suggests the same.



1 - 35

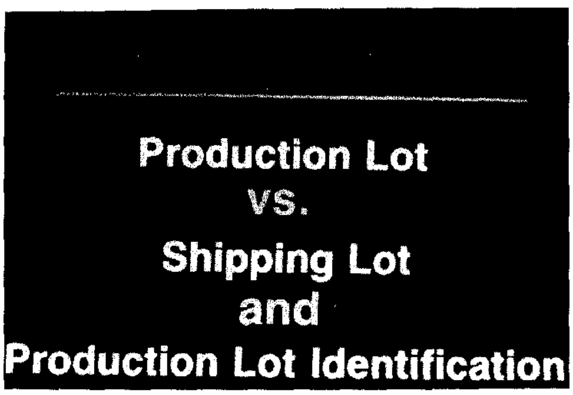
The snug tight concept has not been well understood and/or not properly applied. Improper usage has resulted in inadequate bolt tension. This problem is complicated by issues concerning material thickness, number of plies, installation procedure, and not knowing when a joint is compacted.



1 - 36

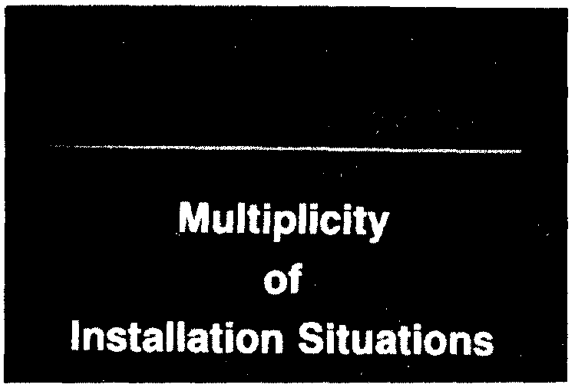
Fasteners with dry, dirty, and rusty thread surface conditions do not install properly and result in inadequate bolt tension. Such thread conditions cause torque measurements to vary significantly. Recognizing this problem, AASHTO had temporarily eliminated the calibrated wrench method from AASHTO Standard Specifications for installation of high-strength fasteners. Though currently permitted by the specifications, this method is not often used.

1 - 37



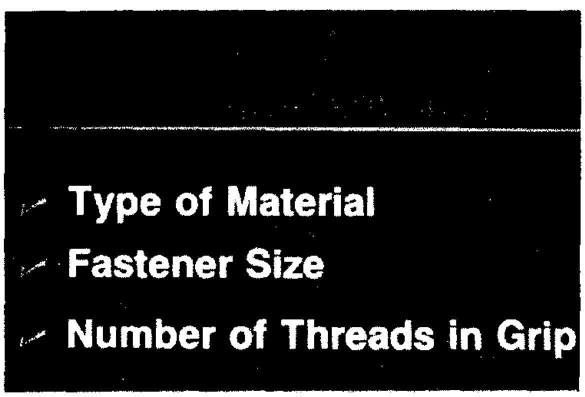
1 - 38

The shipping lot method allows for intermingling different lots of nuts and bolts. For example, bolts of the same length and diameter for a specific purchase order are considered to be the same shipping lot even though they may be from different production lots or different manufacturers. Herein lies the problem: lack of uniformity of product can lead to possible non-uniform behavior of the fasteners and fastener assemblies.



1 - 39

Current AASHTO Standard Specifications for Highway Bridges allows installation of high-strength fasteners by several different methods; turn-of-nut, calibrated wrench, direct tension indicators, or alternate design fasteners. Upon completion of installation, the AASHTO specifications require inspection using a procedure which is a variation of the calibrated wrench installation method. By its nature, this inspection procedure is subject to the many inaccuracies and variabilities of the calbrated wrench installation method, and must be fully understood by the inspector, else fasteners may be erroneously judged acceptable. This inspection procedure will be discussed in depth later.



1 - 40

Inadequate ductility can either prevent the fastener assemblies from achieving required tension in the bolt during installation or reduce their capability to absorb energy when load is applied. Various factors are known to influence ductility of an assembly. These include:

(a) Type of Material (A325 vs. A490)*

(b) Fastener size (length, diameter etc.)

(c) Number of threads in the grip

*Comparable size of ASTM A490 (AASHTO M253) bolt assemblies have been observed to be less ductile than ASTM A325 (AASHTO M164) bolt assemblies.

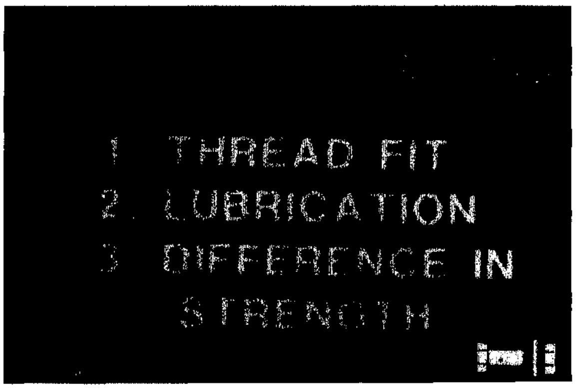
Session 2

Theory and Behavior of Structural Bolts and Connections

2 - 1

BOLT THEORY AND BEHAVIOR

The fastener assembly is governed by three different AASHTO or ASTM product specifications. Additional specifications spell out the geometry of each component as well as the thread dimensions. The behavior of the fastener is dependent upon a combination of strength and geometry variables. The existing specifications do not require the testing of the assembly to insure it will perform satisfactorily. This presentation discusses the significant variables associated with the behavior of the fastener assembly.

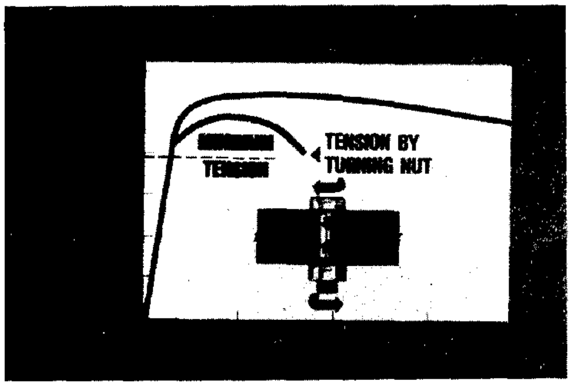


2 - 2

The interaction of these variables dominates the tightening performance of the structural fastener. Each of these will be discussed.

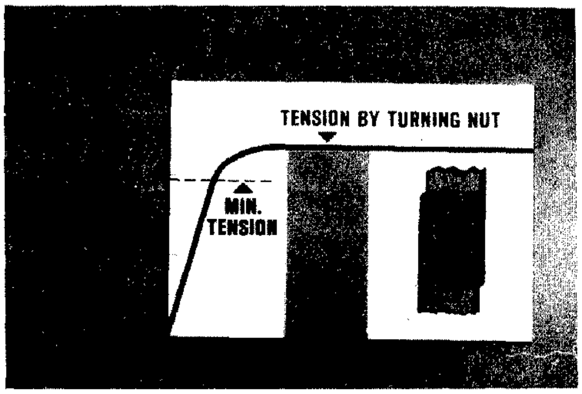
2 - 3

The goal of this course and the modifications to the AASHTO or ASTM specifications presented are to insure that upon installation, the fastener assembly will perform in a consistent manner. The fastener can be installed easily and reliably. The required installation tension can be attained using normal procedures.



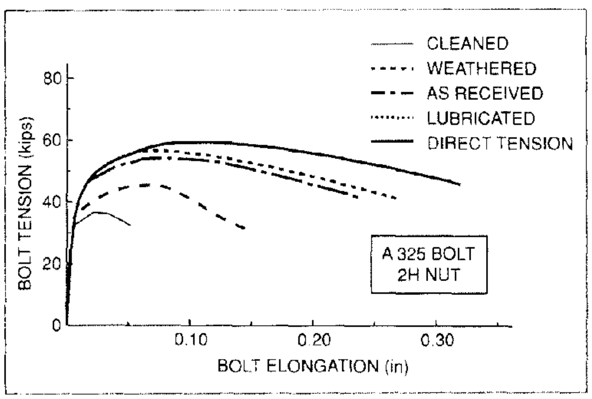
2-4

Tensioning a bolt by turning the nut introduces torsion as well as tension into the bolt. The torsion comes from the friction between the threads of the nut and bolt. The resulting combined state of stress produces a reduction in ductility and tensile strength of the bolt. Larger torsion caused by lack of lubrication of the threads can cause a drastic reduction in the tension that can be attained by tightening the nut.



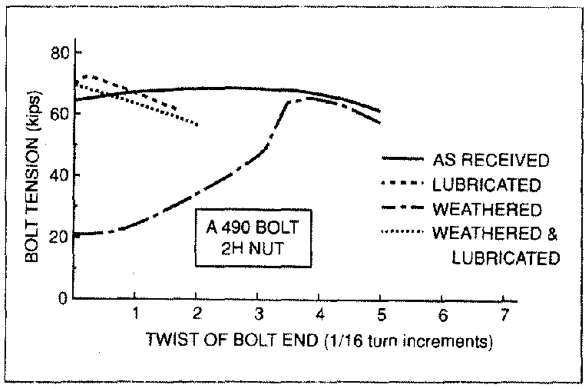
2-5

The desired performance of a fastener assembly is shown in Figure 2-5. A flat-ductile plateau in the turn versus tension behavior is desired. Slight overturning of the fastener will not cause a reduction in tension or lead to failure. Variations in the applied turns will not cause a significant variation in the bolt tension. The actual bolt tension will exceed the required pretension if the bolt is tightened into the inelastic region using the turn of the nut installation procedure.



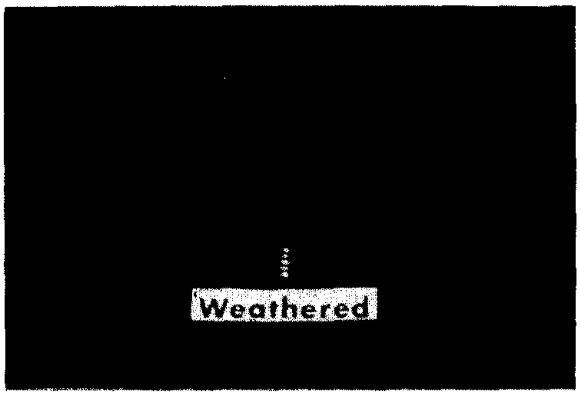
2-6

Figure 2-6 shows the behavior of the same fastener assembly tensioned by turning the nut with various conditions of the threads. The drastic reduction in the tension and ductility of the assemblies with weathered and cleaned thread conditions is caused by the higher torsion introduced into the bolt. Thread lubrication is an important variable.



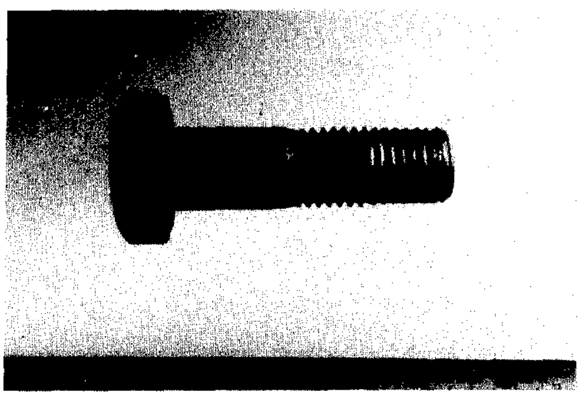
2-7

Figure 2-7 shows the rotation of the bolt at the nut end. The head of the bolt was prevented from twisting. The rotation of the bolt end indicates the magnitude of the torsional force in the bolt. Assemblies with poor thread lubrication introduce much higher twisting deformation and forces in the bolt.



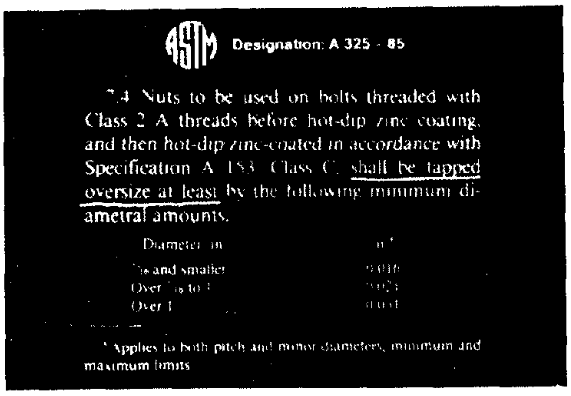
2-8

The weathered assemblies tested were in the condition shown in Figure 2-8. The water soluble oil was removed by dunking the nut and bolt individually into water. The slight rusting of the nut threads can be seen in the slide. Maintaining thread lubrication in the field is important and requires proper fastener storage at the job site.



2-9

Galvanized and coated fasteners require special consideration. Galvanizing increases the size of the threads which cause problems with the fit. Soft galvanizing also causes galling of the threads, increasing the twisting force introduced into the bolt.


Designation: A 325 - 85

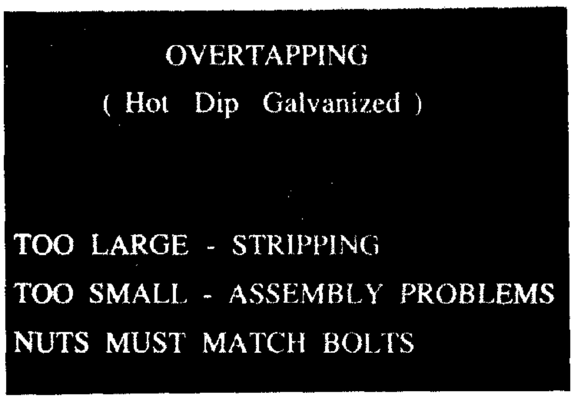
7.4 Nuts to be used on bolts threaded with Class 2 A threads before hot-dip zinc coating, and then hot-dip zinc-coated in accordance with Specification A 153 Class C, shall be tapped oversize at least by the following minimum diametral amounts.

Diameter, in.	in.[A]
[illegible] and smaller	[illegible]
Over [illegible] to [illegible]	[illegible]
Over 1	[illegible]

[A] Applies to both pitch and minor diameters, minimum and maximum limits.

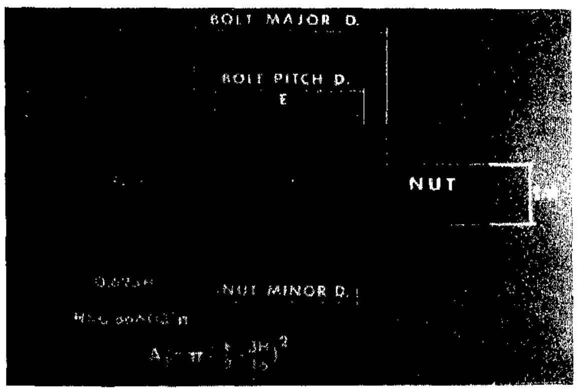
2 - 10

The present specification requires that the nut be overtapped by the minimums shown in Figure 2-10. These requirements ensure that the nut can fit the larger thread on the bolt. However, the specification can result in a nut with threads too large to develop the strength of the bolt, since it only specifies a minimum not a maximum. Research indicates that these minimums are closer to the maximum values that should be employed. The FHWA memorandum does not specify an overtap size. The manufacturer can use whatever is required to produce thread fit and strength.



2 - 11

The amount of overtapping that can be allowed is dependent upon the strength of the nut and bolt. Thread stripping occurs when the strength of thread area engaged in the nut is not sufficient to develop the force generated in the bolt.

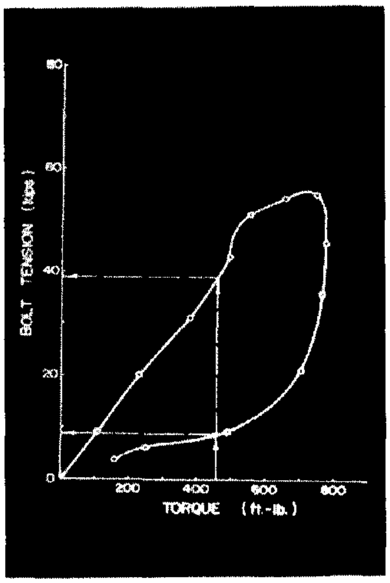


2 - 12

Stripping should not occur in a proper fastener assembly. The increase in the nut thread diameter caused by overtapping reduces the thread shear area.

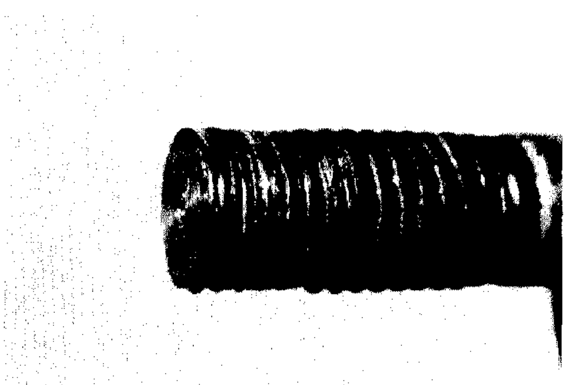
2 - 13

High-strength heat treated nuts are required for galvanized fasteners. The high strength of the nuts compensate for the loss of thread cross section from overtapping.



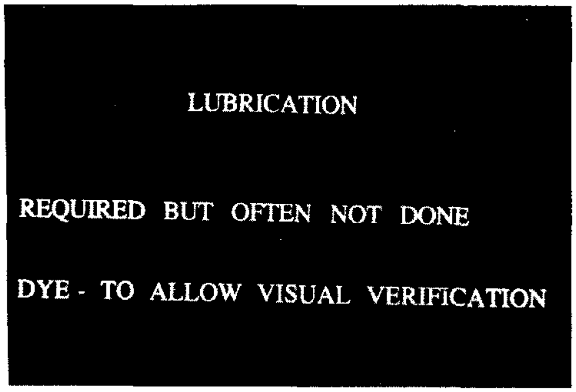
2 - 14

Stripping, which is a thread shear failure, causes the tension versus torque relationship shown in Figure 2-14. Measurement of the torque on a stripped fastener does not provide a reliable indication of tension. Also, the tension developed in the fastener may be much less than required.



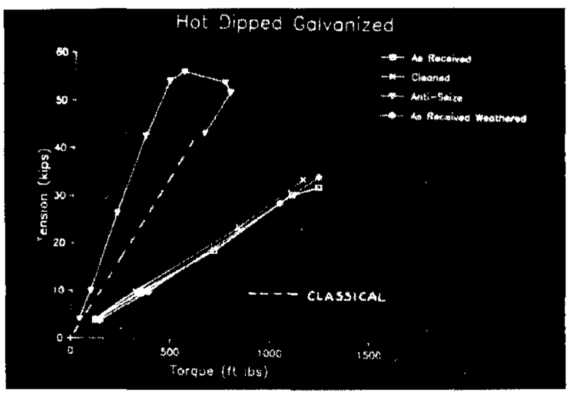
2 - 15

This is a bolt with stripped threads. A proper fastener assembly will fail by fracture through the threads of the bolt outside the nut.



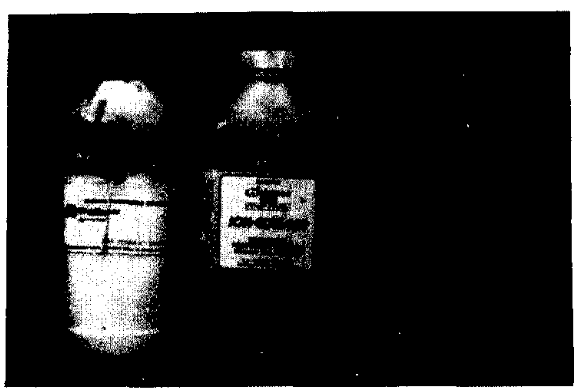
2 - 16

Lubrication is more critical on coated fasteners. The soft zinc on the treads can lead to galling and lock up of the threads. Lubrication prevents the occurrence of thread lock up and reduces the twisting force introduced into the bolt. Lubrication of the nut is required in the present specifications. Lubrication does not reduce stripping. Lubrication may actually increase the tendency to strip by allowing the threads to slide in the diametric direction.



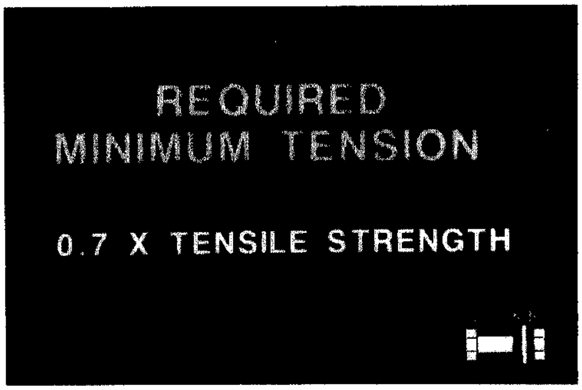
2 - 17

The importance of thread lubrication upon the tightening behavior of a galvanized bolt is shown in Figure 2-17. The as-received and cleaned assemblies produced identical results, indicating the bolts were not properly lubricated as required in the specifications. The as received bolts could not be installed to the required pretension using normal equipment. Lubrication of the nuts produced excellent results.



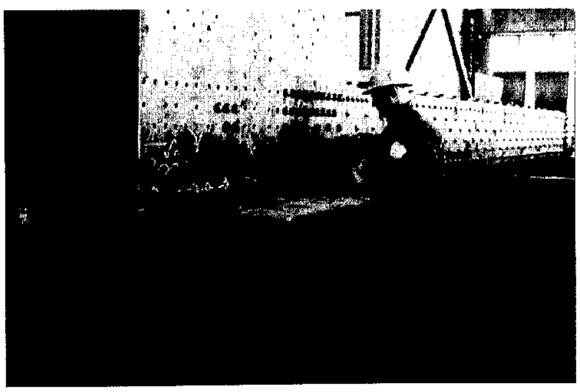
2 - 18

The commercial water soluble lubricants on the left are used by the manufacturer to lubri cate the nuts. Stick waxes can be used in the field to relubricate the fastener assemblies if the water soluble lubricant has been washed away by water due to improper storage of the fasteners.



2 - 19

High-strength bolts used in bridge construction are required to be installed to an initial pretension equal to or greater than 0.7 tines their tensile strength. Note that the requirement is bolt tension, not a particular torque value. Torque may be used only if the requirements for calibrated wrench installation are followed.

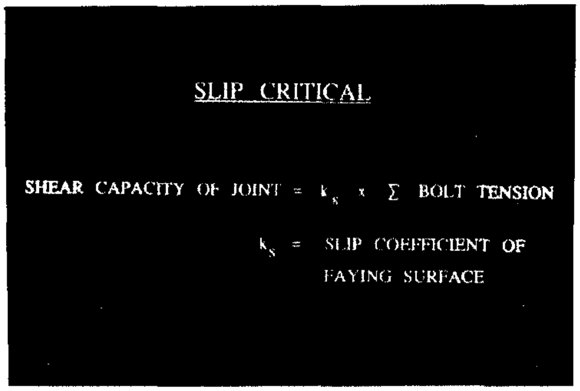


2 - 20

The purpose of the installation tension is not only to ensure that the bolt does not loosen, but also to insure the connection behaves consistent with the structural requirements.

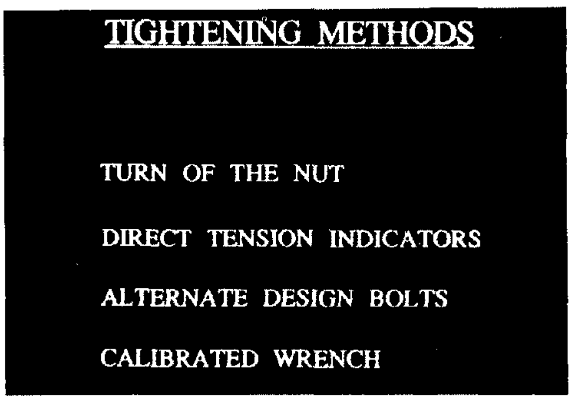
2 - 21

Two types of connection designs for shear are used in highway bridges. Slip critical connections are normally used for most connections. Bearing connections, connections which rely on bolt shear strength, are used in compression members or secondary members only. All connections, however, must satisfy the bolt shear strength requirements at maximum load.



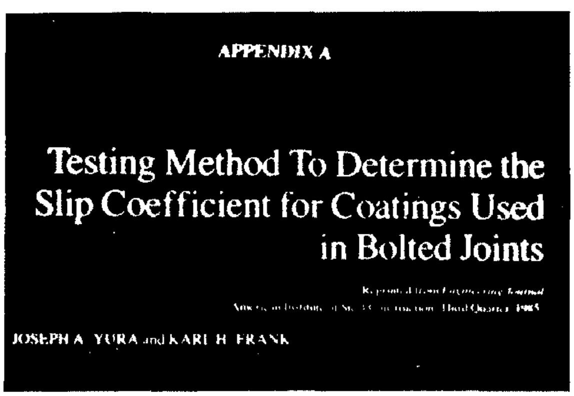
2 - 22

The installed bolt tension applies a clamping force to the plates in the connection. The plates will not slip relative to one another until the friction capacity is exceeded. The sum of the bolt tensions in the connection times the slip coefficient of the plate surfaces in contact (the faying surfaces), equals the slip load of the connection. Proper bolt tension is required for the connection to attain the design slip capacity.



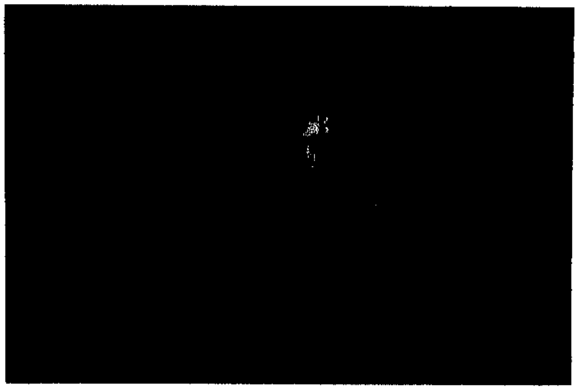
2 - 23

Four tightening methods are recognized in the specifications. The purpose of these methods is to insure that the bolts have the required installation tension. The changes in the nut and bolt specifications and the rotation capacity test are designed to insure that the fasteners are capable of being installed by any of these methods.



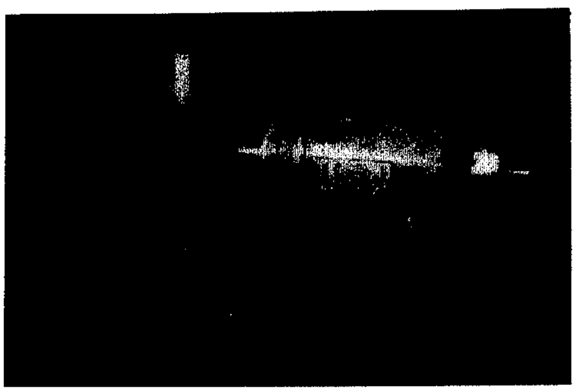
2 - 24

Paints or coatings used on the faying surface of a bolted connection are to be tested using the test method developed in a research study sponsored by the FHWA. The test method determines the slip coefficient of the coating and its creep behavior. The testing method was translated into a specification by the Research Council on Structural Connections. The tests are normally performed for the manufacturer by an independent laboratory. Some States have undertaken their own testing program.



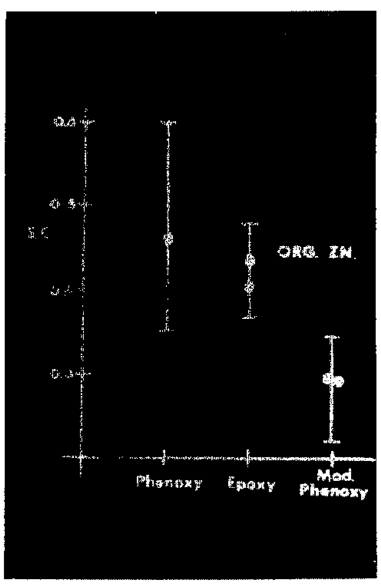
2 - 25

Small 4-inch square plates are used for the initial slip tests. They should be coated using the same procedures to be used on the job. They are to be coated to a thickness 2 mils greater than the average thickness to be used on the structure. The added thickness is to insure that a buildup of paint at a connection does not reduce the connection's slip capacity.



2 - 26

The slip specimen consists of three of the coated plates. The bolt tension is applied using a center hole ram with a 7/8-inch high-strength rod passing through it. The shear force is applied to the center plate by a compression test machine. The slip coefficient of the specimen is the slip load divided by twice the clamping force, since two slip planes are contained in the specimen.



2 - 27

Paints with the same generic title do not have the same slip coefficient. All of these paints are organic zinc rich paints. Each had produced a different slip coefficient. The test method provides a simple means of insuring the paints applied have a slip coefficient compatible with the design requirements of the connection.

2 - 28

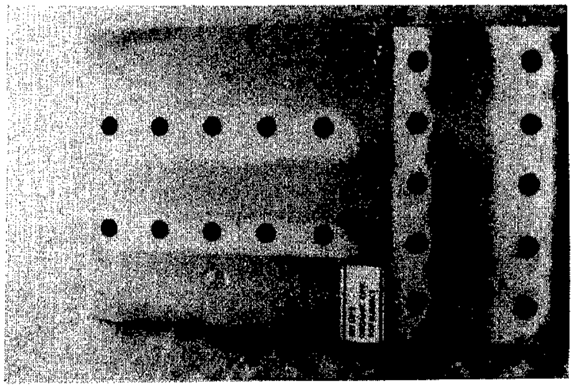
Some paints, particularly vinyl and organic zinc-rich paints, exhibit creep under sustained loading. The testing method requires a 1,000 hour creep test. The load applied to the specimen is dependent upon the results of the small slip coefficient specimens. After 1,000 hours the specimens are loaded to the minimum design load.

2 - 29

The results of creep tests of an inorganic zinc-rich paint with a vinyl top coat are shown in the slide. Thicker coatings have larger creep deformation than thinner coatings. Creep deformation also increases with an increase in the applied shear load. The thick coating slipped into bearing at 20% of the small specimen test slip load in less than 10 days.

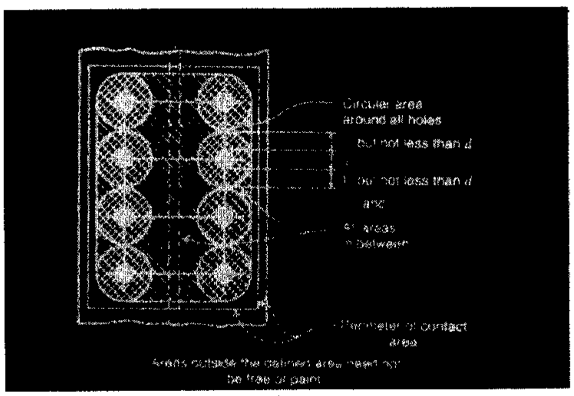
2 - 30

Large scale bolted connection tests were used to verify the accuracy of the results from the small specimens employed in the test method. The agreement was excellent. Painting of the faying surfaces reduces fabrication cost by eliminating masking. It also increases the coating life of the structure by eliminating corrosion at the uncoated crevices at the edges of the connection.



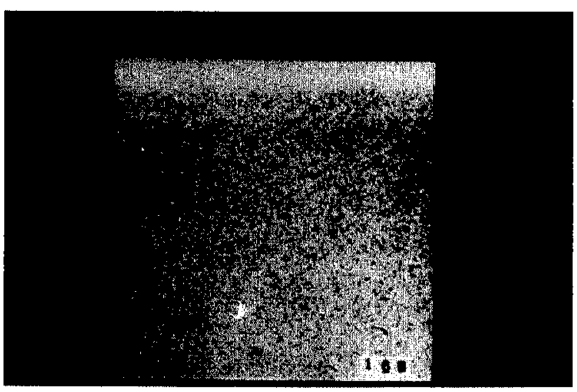
2 - 31

Shown in Figure 2-31 are the splice plates from one of the large tests after testing. Evidence of slip on the surface of the plates is only visible in the area directly under the bolt. This is due to the distribution of the bolt clamping forces between the plates. The slip coefficient of the plates remote from this contact area does not effect the slip load. Also, it is not necessary to have the outer edges of the plates in contact since only the area directly under the bolt participates in the slip resistance of the connection.



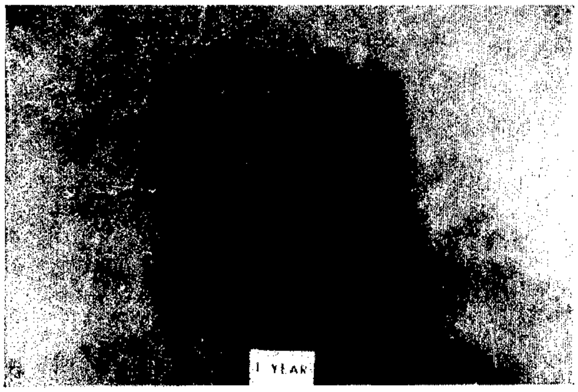
2 - 32

The specification commentary recognizes that only the area local to the bolt influences slip behavior. Figure 2-32 shown is from the commentary of the Research Council Specifications. The shaded areas are the portions of the faying surface which must have the required coating or lack of coating if a mill scale or blasted surface is specified. The portions of the faying surfaces outside of the shaded area will not influence the slip performance of the connection. This figure can also be used to indicate the areas of a connection which must be brought into contact during the snugging of the bolts. Often, due to curvature of a plate, it is not possible to bring the edges of the plate into contact. This is not a concern if the shaded areas of the plate are in contact.



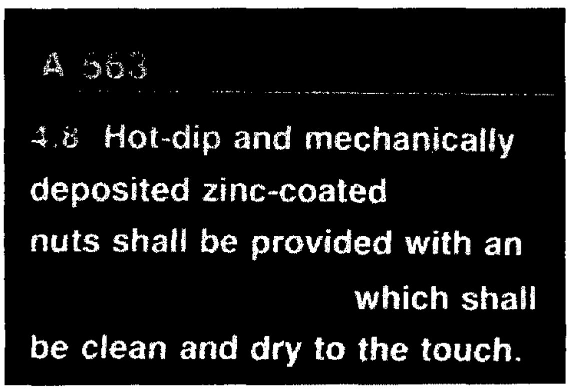
2 - 33

The shaded areas must be protected against overspray from coatings such as top coats, which are not desired on the faying surfaces. The small amount of overspray shown on this plate will cause the slip coefficient of the connection to be changed to the value of the oversprayed paint.



2 - 34

Weathering steels which were either blasted or had the mill scale left in place were tested after one year of exposure. Figure 2-34 shows the typical surface of the plates after exposure. The results showed that the rusting of the plates did not significantly reduce the slip coefficient of the plate surface. Tight rust does not have to be removed from unprotected surfaces. Loose scale or rust must be removed prior to making the connection. The removal should be done by blasting or hand brushing. Power wire brushing should not be used since it polishes the surfaces.

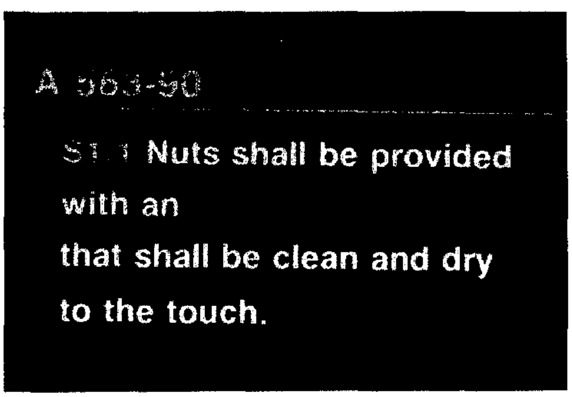


2 - 35

LUBRICANTS

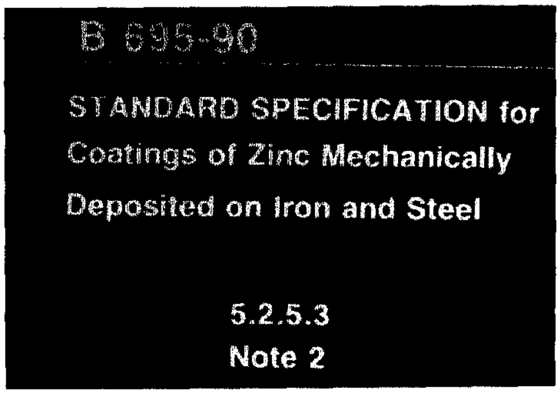
ASTM A563 (AASHTO M291) specifications have mandated the use of lubricants on galvanized nuts for years.

Also Note D of Table 3 of these specifications allows the substitution of an A194 2H nut for a Grade DH nut when used on an A325 bolt, but nowhere in the specification does it state specifically that A194 2H zinc coated nuts are to be lubricated. The intent of this specification is, however, that if galvanized A194 2H nuts are substituted for galvanized Grade DH nuts that they shall be lubricated.



2 - 36

This later supplemental section allows any grade of nut covered by A563 to receive a clean, dry to the touch lubricant, provided S1.1 is invoked.



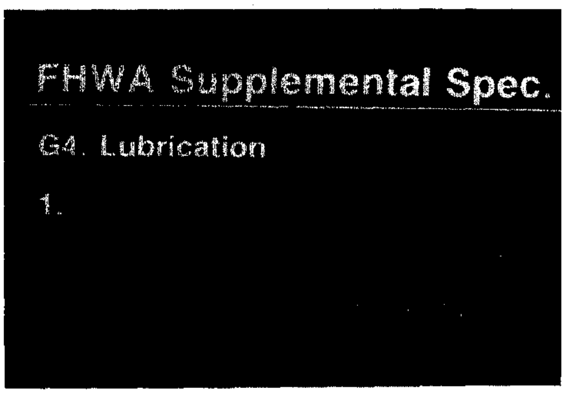
2-37

The mechanical galvanizing specification has now been modified to include the following:

5.2.5.3 Lubrication of Grade DH nuts processed in accordance with this specification and used with Specification A325 high-strength bolts is a requirement of paragraph 6.5 of Specification A325 and paragraph 4.8 of Specification A563.

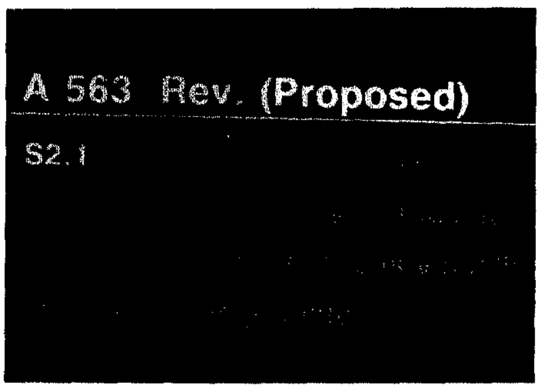
and

Note 2 - Although not included in Specification A194/A194M, this provision should apply to mechanically galvanized A194 2H nuts when supplied for use with Specification A325 bolts.



2-38

An inability to detect clean, dry to the touch lubricant coatings has led the FHWA to mandate the use of a "visible lubricant" so that its presence is obvious. This supplemental FHWA Specification was issued after a recent University of Texas report which indicated that fastener failures studied as part of their FHWA funded program were in part due to lubricants not having been applied. Coloring of the lubricant was a way to provide visibility and a reasonable assurance that a lubricant had in fact been applied.



2-39

ASTM has responded by providing a proposed supplemental section, S2.1, in which, when specified by the purchaser, mandates that the lubricant be "visually obvious" at the job site. These requirements have led to the inclusion of dyes and colorants to lubricant systems.

UV Detectable Lubricants

- Predictability
- Verifiable
- Easy to use
- Easy to handle
- Clean and safe

2 - 40

Ultraviolet detectable lubricant systems substitute UV tracers for dyes and colorants. They are detectable under a variety of UV lighting systems including portable and hand-held elements.

SUMMARY

Galvanized Nuts:

- Visible lubricant

Black Bolts:

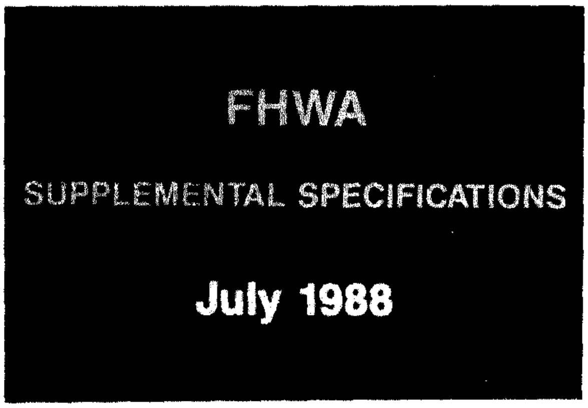
- Oily to touch when delivered and installed

2 - 41

In summary, galvanized nuts shall be lubricated with a visible lubricant. The use of UV detectable lubricants has not been specifically addressed by the specifications.

Black bolts (and presumably nuts) shall be oily to the touch when delivered and installed.

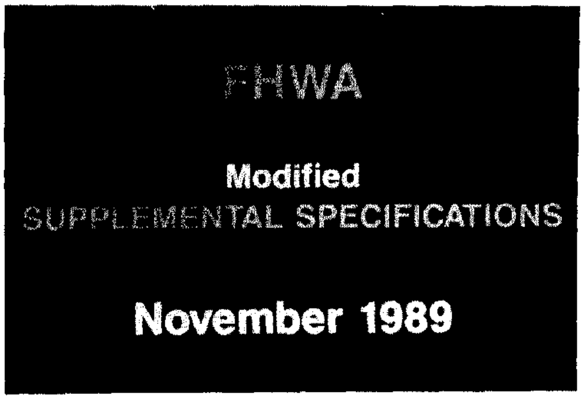
Session 3
FHWA Requirements for High Strength Bolts



3 - 1

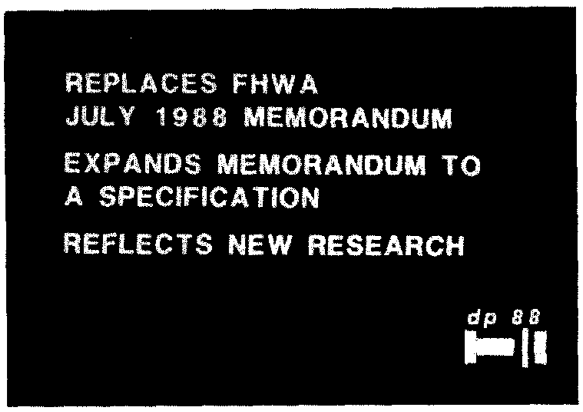
FHWA SUPPLEMENTAL SPECIFICATIONS

The FHWA first issued supplemental specifications to underscore various recommendations and to implement recommendations made in the FHWA-sponsored research report, *High-Strength Bolts for Bridges*.



3 - 2

The modified supplemental specifications issued by FHWA in November 1989 are in a ready-to-use specification format with needed clarification and can be incorporated in the contract if required. The modifications also reflect new research and input from the industry.



3 - 3

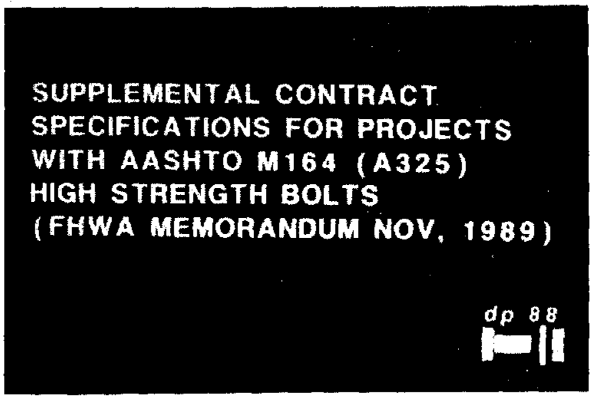
3-4

CONVENTIONAL PRACTICES AND CURRENT SPECIFICATIONS FOR HIGH STRENGTH BOLTS

Generally, the States have been using "AASHTO Materials Specifications" and "AASHTO Standard Specifications for Bridges" and ANSI Specifications as applicable to high-strength bolts along with special provisions to a project.

Consideration is being given to revise fastener specifications in "AASHTO Materials Specifications" and "AASHTO Standard Specifications for Bridges, Division II."

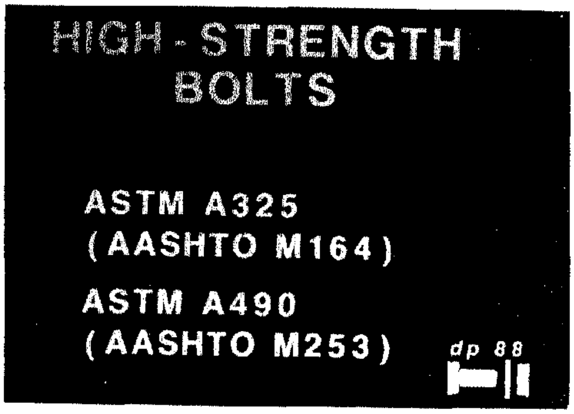
ASTM Subcommittee F16.02 is also considering revisions to current specifications for fasteners.



3-5

3-6

RCSC approved "Specification for Structural Joints using ASTM A325 or A490 Bolts" is a very good reference source which includes a very useful commentary.

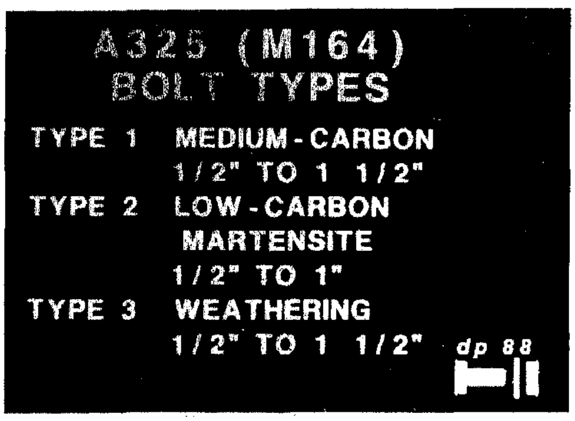


3 - 7

HIGH-STRENGTH BOLTS

Generally, A325 (M164) bolts are used in bridge work.

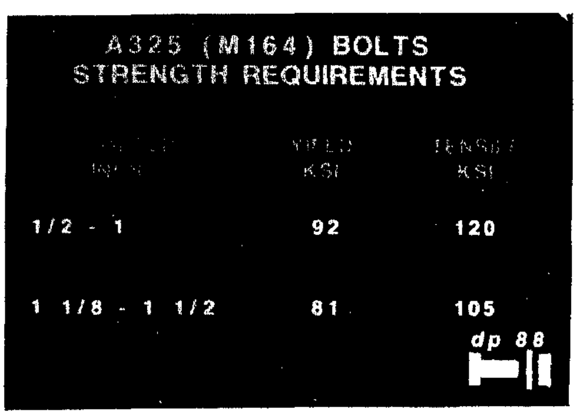
AASHTO allows A490 (M253) bolts also.



3 - 8

A325 (M164) BOLT TYPES

A325 bolts are available as types 1, 2 and 3. Type 2 steel is no longer manufactured in U.S. ASTM is considering eliminating this type.



3 - 9

A325 (M164) STRENGTH REQUIREMENTS

A325 (M164) fasteners require minimum tensile strength of 105 ksi for 1 1/8 to 1 1/2-in. diameter bolts and 120 ksi minimum strength for 1/2 to 1-inch diameter bolts.

A325 (M164) BOLTS HARDNESS REQUIREMETNS

DIAMETER (IN.)	MINIMUM	MAXIMUM
1/2" - 1"	24	35*
1 1/8" - 1 1/2"	19	31

*RECOMMENDED IN THE FHWA SUPPLEMENTAL SPECIFICATIONS - 33Rc

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3 - 10

A325 (M164) HARDNESS REQUIREMENTS

ASTM and AASHTO Materials Specifications provide a range of hardness, but these specifications do not include upper bound of tensile strength for A325 (M164) bolts. Of course, the hardness can be converted to an equivalent tensile strength using conversion tables. (For example see conversion tables in ASTM A370).

MATCHING NUTS

A325 (M164)	A 563 (M291)	A194 (M292)
TYPE 1 & 2 PLAIN	C, C3, D, DH & DH3	2, 2H
TYPE 1 & 2 GALV.	DH & DH3	2H
TYPE 3	C3, DH3	-

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3 - 11

MATCHING NUTS

FOR A325 (M164) BOLTS

- Type 3 bolts may be used in lieu of type 1 or 2 uncoated bolts.
- Matching nuts for A325 (M164) bolts include nonheat-treated nuts 2, C, C3 and D in addition to heat-treated nuts 2H, DH and DH3.
- Only heat-treated nuts are galvanized.
- Overtapping and lubrication requirements for A194 (M292) grade 2H nuts are the same as those for A563(M291) nuts.

NUT HARDNESS REQUIREMENTS

PLAIN NUTS-A563(M291) & A194(M292)

GRADE	MIN.	MAX.
C&C3	B78	C38
D	B84	C38
2	B84	-
RECOM.	B89	C38

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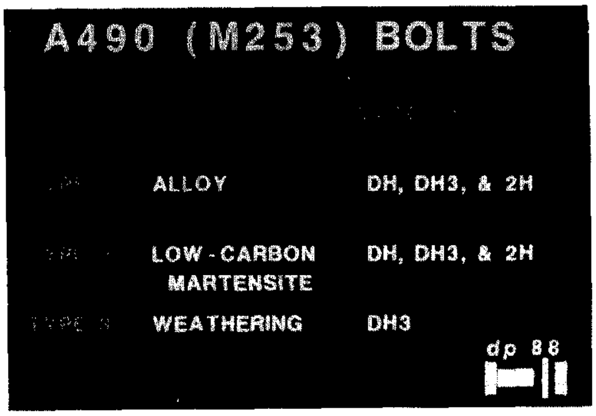
3 - 12

NUT HARDNESS REQUIREMENTS

FOR A325 (M164) BOLTS

These nonheat-treated nuts can have hardness as low as 78 HRB. (The FHWA recommends a minimum hardness of 89 HRB. This will be discussed later.)

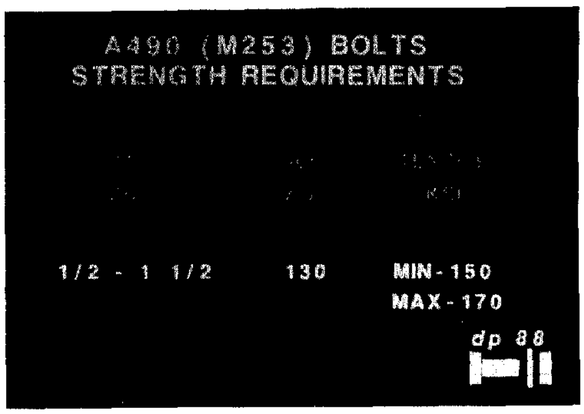
Heat-treated nuts which are often preferred by bridge owners have higher hardness.



3 - 13

A490 (M253) BOLTS & MATCHING NUTS

- A490 (M253) bolts are available as types 1, 2 and 3.
- A490 (M253) bolts are not galvanized.
- Only heat-treated hardened nuts are permitted as matching nuts of A490 (M253) bolts.



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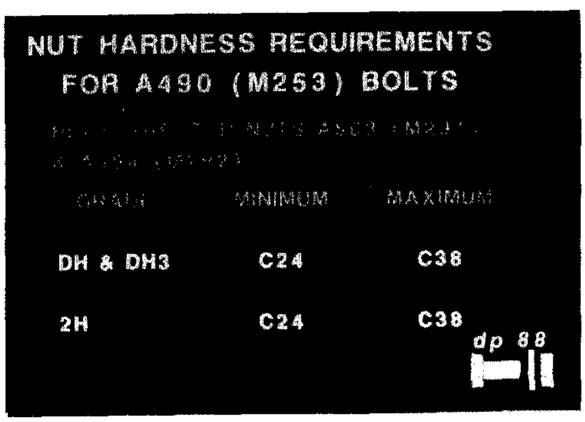
A490 (M253) STRENGTH REQUIREMENTS

Specified strength of A490 (M253) bolts range from 150 ksi to 170 ksi.

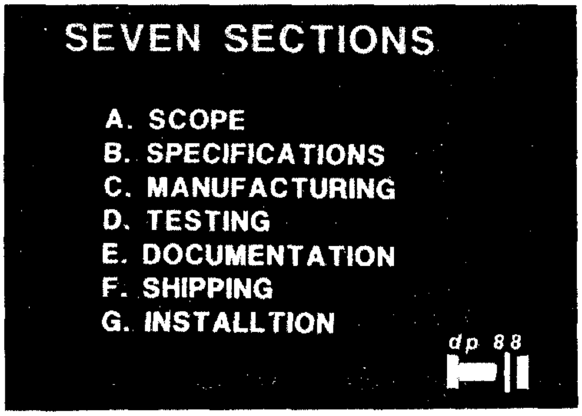


3 - 15

NUT HARDNESS REQUIREMENTS FOR A490 (M253) BOLTS

Heat-treated hardened nuts with minimum hardness C24 are permitted.

Note: (C24>>89HRB)



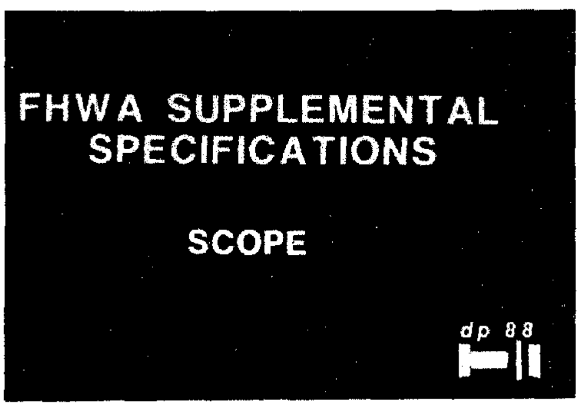
3 - 16

<u>FHWA SUPPLEMENTAL SPECIFICATION</u>
(FHWA Memorandum Nov. 8, 1989)

"FHWA supplemental specifications for projects with AASHTO M164 (A325) high-strength bolts" contains seven sections.

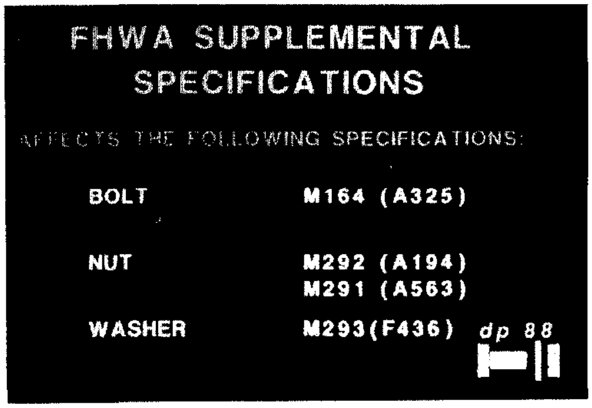
3 - 17

The FHWA supplemental specifications amend or revise AASHTO Material Specifications, but do not replace them.



3 - 18

The supplemental specifications cover requirements for M164 (A325) bolts, matching nuts, and washers only. Similar requirements for other fasteners are under consideration.

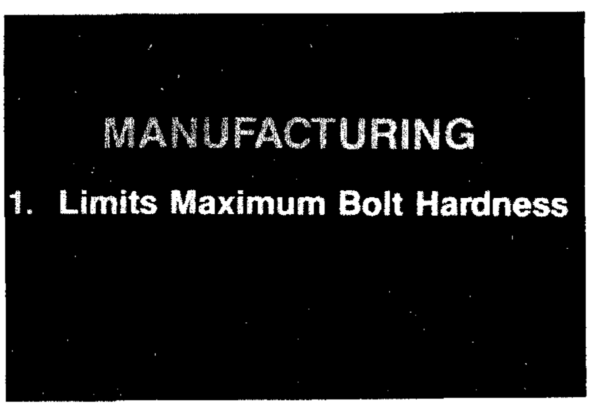


3 - 19

SPECIFICATIONS

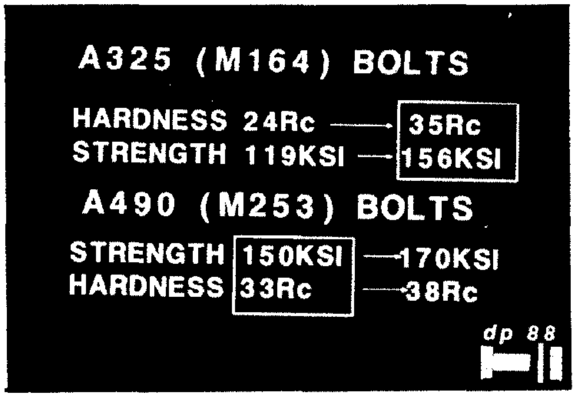
3 - 20

MANUFACTURING



3 - 21

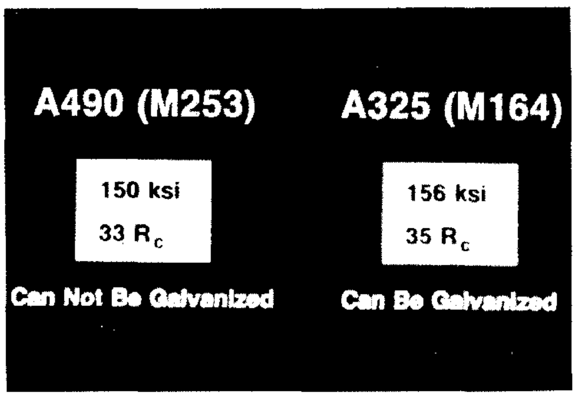
The FHWA supplemental specifications limit M164 (A325) bolt hardness of 1/2 inch to 1 inch dia. bolts to the maximum hardness of 33Rc. Because the maximum required hardness is 31Rc for bolts greater than 1 inch diameter, in the AASHTO Materials Specifications, no changes in the hardness requirements are proposed for larger-diameter bolts.



3 - 22

<u>INCONSISTENCY IN THE CURRENT REQUIREMENTS FOR STRENGTH AND HARDNESS OF BOLTS</u>

ASTM and AASHTO Materials Specifications allow maximum hardness of 35Rc for A325 (M164) bolts. This is equivalent to a tensile strength of approximately 156 ksi. Because specifications allow galvanizing of A325 (M164) bolts, it is possible to allow galvanizing of A325 (M164) bolts which may have 35Rc hardness and approximately 156 ksi tensile strength.



3 - 23

However, the current practice is to prohibit galvanizing A490 bolts, which can have hardness as low as 33Rc and tensile strength as low as 150 ksi.

3 - 24

<u>RECOMMENDED MAXIMUM HARDNESS FOR A325 (M164) BOLTS</u>

The FHWA supplemental specifications limit A325 (M164) bolt hardness to 33Rc for bolts 1/2 inch to 1 inch diameter.

MANUFACTURING

2. Increases Hardness Requirements for Non-Heat Treated Nuts

3 - 25

NUTS

Minimum hardness of 89 HRB is required for non hardened nuts. (Heat-treated nuts have hardness > 89 HRB).

WHY MINIMUM HARDNESS OF 89 HRB?

3 - 26

WHY MINIMUM HARDNESS OF 89 HRB?

Alexander's model helps explain why 89 HRB minimum hardness must be required for nonheat-treated nuts if stripping of nuts must be controlled.

The curves have been plotted for A325 bolts of 7⁄8 inch diameter and 156 ksi tensile strength (equivalent to 35Rc hardness).

STRIPPING can be controlled using heat-treated nuts 2H, DH, DH3, or nonheat-treated nuts 2, C, C3 and D provided nonheat-treated nuts have strength > 87 ksi, i.e. hardness > 89 HRB.

3 - 27

The stripping strength represents stripping strength of the bolt or the stripping strength of the nut.

Tension strength is tension strength of the bolt.

For a stripping strength/tension strength ratio the failure will occur by nut stripping when the observed nut strength is 87 ksi or less.

87 ksi strength is equivalent to 89 HRB hardness (see conversion table in ASTM A370).

NON-HEAT TREATED NUTS
(2, C, C3 and D)

If Hardness > 89 HRB - NO Stripping

(Tension Failure Rather Than Stripping Failure)

3 - 28

Thus, it can be concluded that non-heat-treated nuts with minimum hardness of 89 HRB would prevent stripping, and tension failure, rather than stripping failure, would result - and that is desirable.

MANUFACTURING

3. Limits Oversize Tapping

3 - 29

<u>NUTS</u>

It is suggested that the amount of overtap in the nut must be such that the nut will assemble freely on the bolt in coated condition and also meet the mechanical requirements of AASHTO M291 (A563) and the rotational-capacity test. The amount of overtap values in M291 (A563) Sec. 7.4 are considered maximum overtapping values.

A563 (M291) SECTION 7.4	MIN. OVERTAPPING IF NUT IS TO BE GALV.
7/16 & SMALLER	0.016 IN.
OVER 7/16 TO 1	0.021 IN.
OVER 1	0.031 IN.
A325 (M164) SECTION 7.3	DIAMETRAL INCREASE IF BLACK BOLT IS HOT-DIP GALV.

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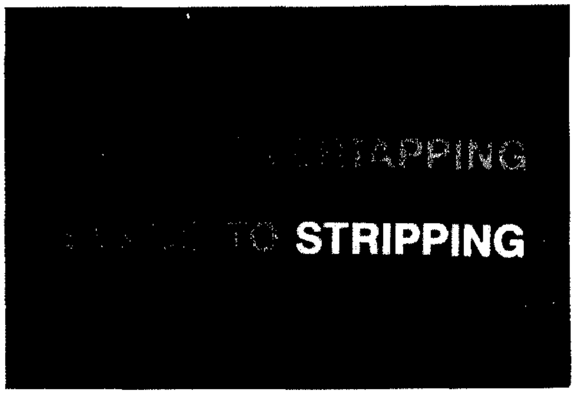
3 - 30

ASTM A563 SECTION 7.4

7.4 Nuts to be used on bolts threaded with class 2A threads before hot-dip zinc coating, and then hot-dip zinc coated in accordance with specification A153 class C, shall be tapped oversize at least by the following minimum diameteral amounts:

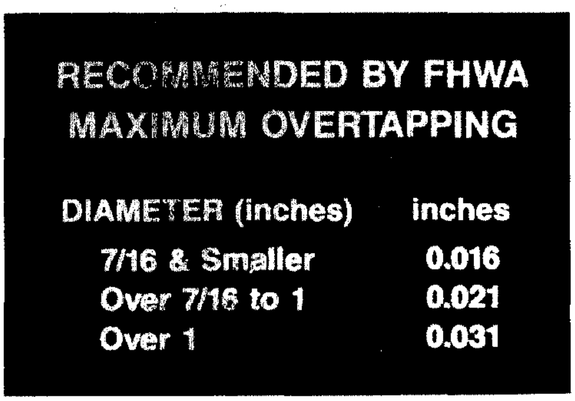
DIAMETER IN.	IN.[A]
7/16 Smaller	0.016
Over 7/16 to 1	0.021
Over 1	0.031

A: Applies to both pitch and minor diameters, minimum and maximum limits.



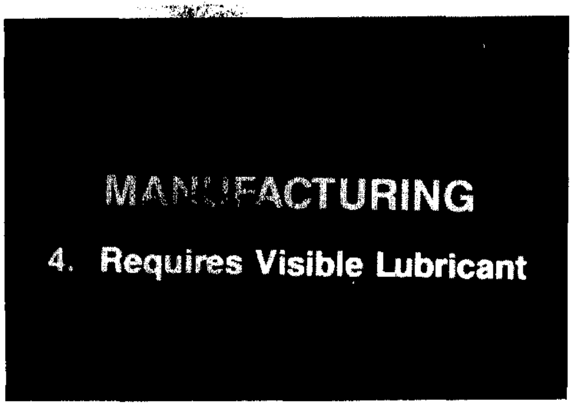
3 - 31

Because large overtapping leads to stripping - the A563M (M291M) specification has been written to ensure that the overtapping requirement is for the maximum limit for overtapping.



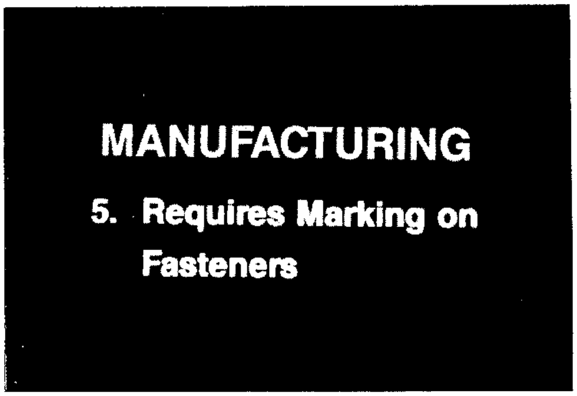
3 - 32

- FHWA supplemental specifications limit maximum overtapping for galvanized nuts.
- FHWA supplemental specifications (November 1989 memorandum) require a fastener assembly to pass the rotational-capacity test.



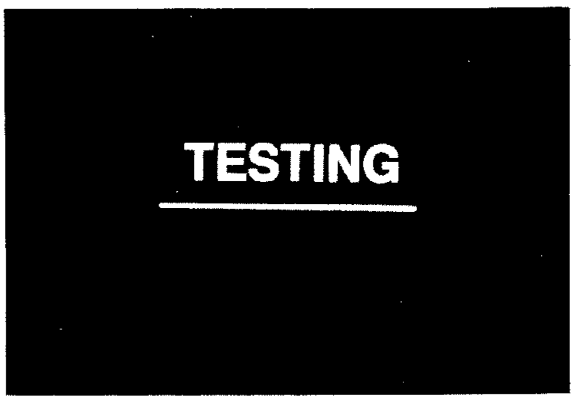
3 - 33

FHWA supplemental specifications require visible lubricant for galvanized nuts and, dry and oily to the touch for black bolts.



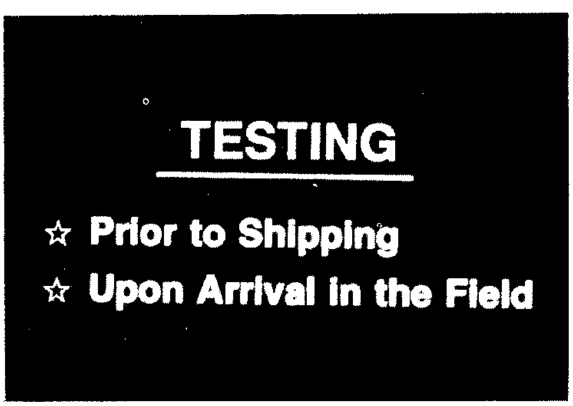
3 - 34

FHWA supplemental specifications require that all bolts, nuts and washers be marked in accordance with appropriate AASHTO/ASTM specifications.



3 - 35

<u>TESTING</u>



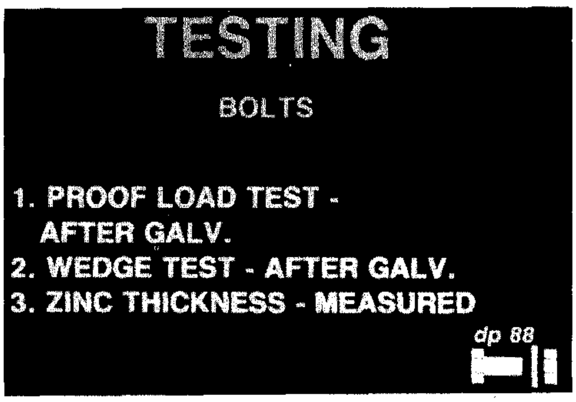
3 - 36

Testing of fasteners is required by the manufacturer or distributor prior to shipping. Also, tests are required in the field.

3 - 37

Mechanical tests are required for:

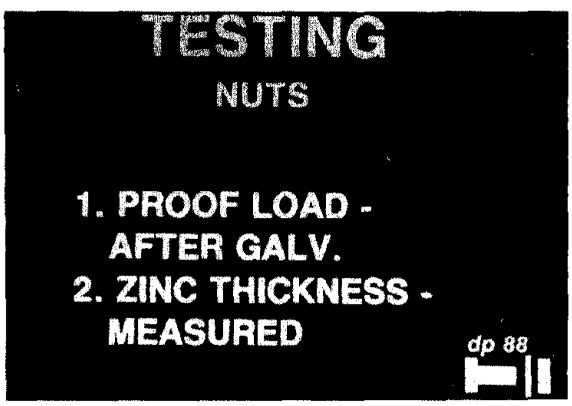
- Bolts
- Nuts
- Washers
- Assemblies



3 - 38

BOLTS

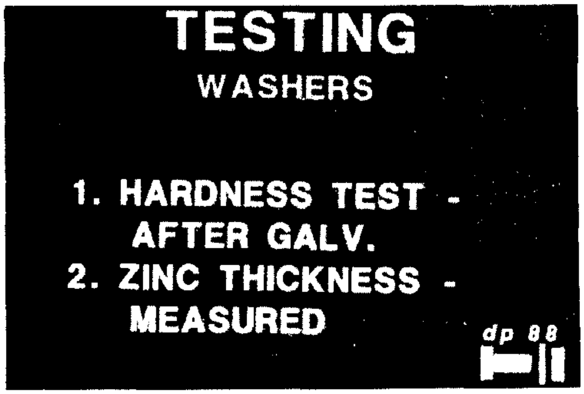
As specified in M164 (A325), minimum frequency of testing for proof load and wedge tests is required. For galvanized bolts, tests are required to be performed after galvanizing. For such bolts zinc coating thickness measurements on wrench flats or top of bolt heads is required.



3 - 39

NUTS

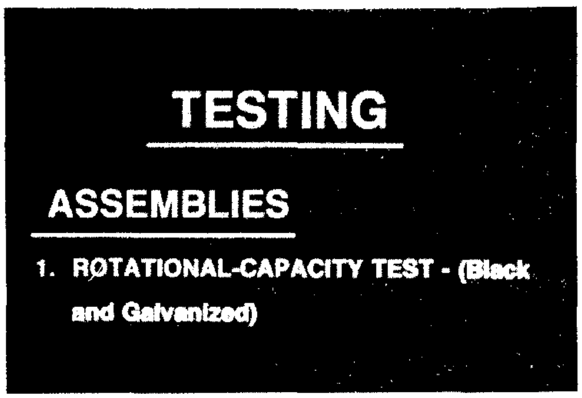
As specified in AASHTO M291 (A563), minimum frequency of proof load testing is required. For galvanized nuts, test are required to be performed after galvanizing. For such nuts, zinc coating thickness measurements on wrench flats is required.



3 - 40

WASHERS

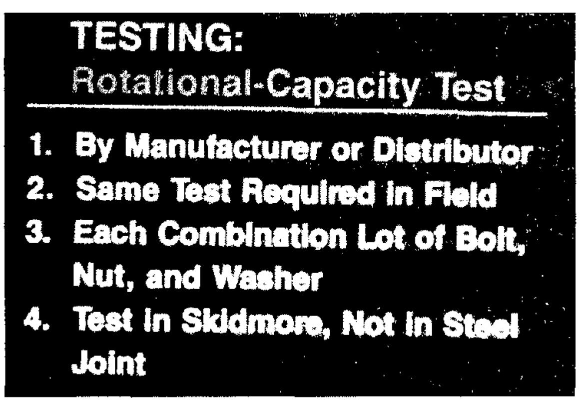
For galvanized washers hardness testing is required after galvanizing. For such washers, zinc coating thickness measurement is required.



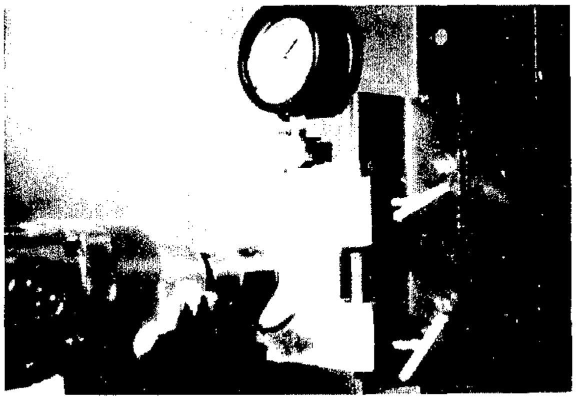
3 - 41

ASSEMBLIES

Rotational-capacity testing is required on all black and galvanized (after galvanizing) assemblies by the manufacturer or distributor prior to shipping.



3 - 42



3 - 43

Washers are required as part of the test even though they may not be required as part of the installation procedure.

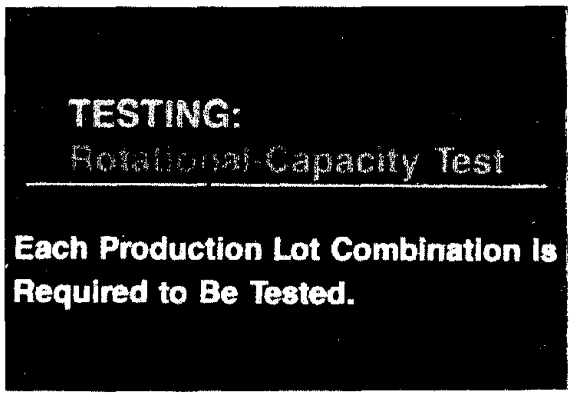
Each combination of production lots of bolts, nuts and washers (when required) is required to be tested as an assembly.

The bolts should show no evidence of stripping after the required turns are applied.

After subsequent loosening of the fastener with a wrench, the nut should be able to turn off by hand (i.e., nut should not bind with the threads of the bolt).

Each combination of production lots of bolts, nuts and washers is required to be assigned a rotational-capacity lot number.

Minimum frequency of testing is 2 per rotational-capacity lot (prior to shipping).



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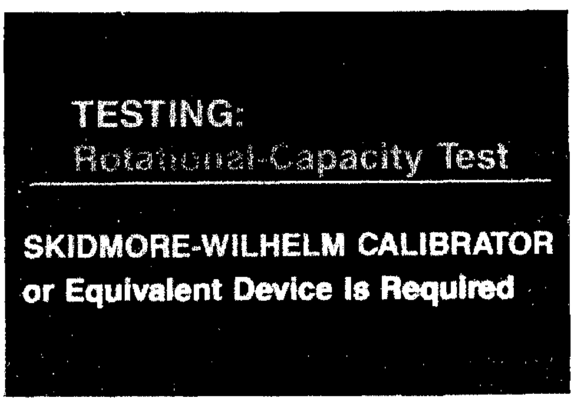
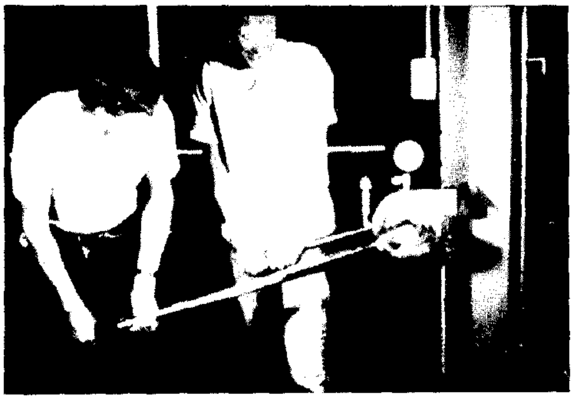


3 - 45

ROTATIONAL-CAPACITY TEST

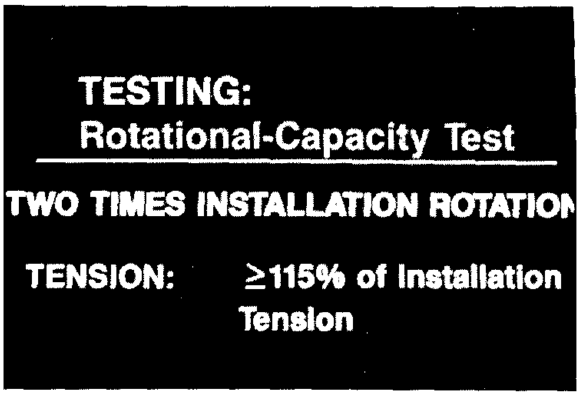
During rotational-capacity testing, bolt tension is required to be measured using the Skidmore-Wilhelm Calibrator or an equivalent device.



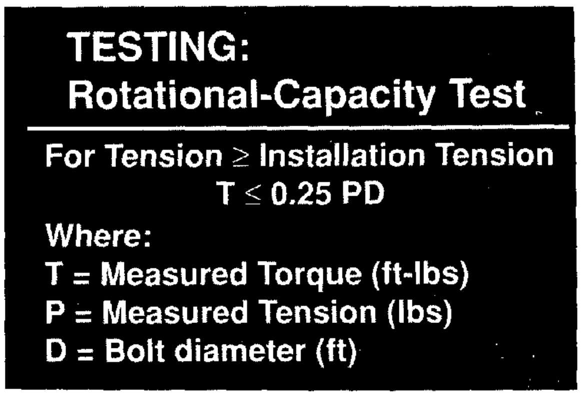
3 - 46

ROTATIONAL-CAPACITY TEST

Steel joints are not permitted except with short bolts.



3 - 47



3 - 48

ROTATIONAL-CAPACITY TEST

The minimum rotation from a snug tight condition (10% of the specified proof load) shall be:

240^{o}	(2/3 turn)	$L < 4D$
360^{o}	(1 turn)	$4D < L < 8D$
480^{o}	(1 1/3 turn)	$L > 8D$

The tension reached at the above rotation shall be equal to or greater than 1.15 times installation tension.

Therefore, required turn test tension for a 7/8 inch diameter M164 (A325) bolt:

= 1.15x39K (req'd. instal. tension)

= 45 kips

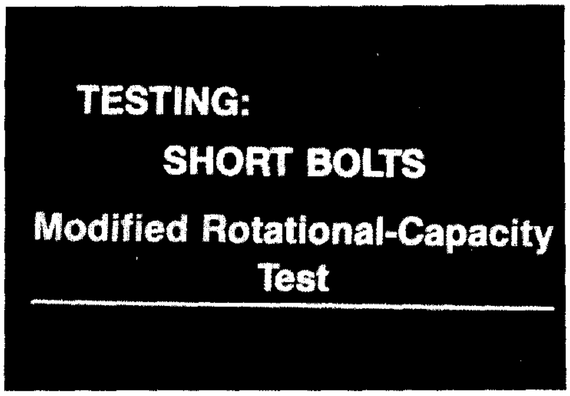
Values of minimum required turn test tension are included in the FHWA supplemental specifications.

After reaching the installation tension, the relationship between torque and tension shall be given by:

$$\text{Torque} \leq 0.25PD$$

Where:

Torque = measured torque (ft.-lbs)
P = measured tension (lbs)
D = bolt diameter (feet)



3 - 49

Short Bolts

Because short bolts would not fit in the conventional Skidmore-Wilhelm Calibrator, it is suggested that the measurement of maximum tension to achieve twice the required installation rotation be omitted. Instead, a value equal to turn test tension (1.15 x installation tension), may be used to compute the torque. The measured torque will be obtained by turning the nut to the minimum rotation (i.e., installation rotation) from the snug tight position in a steel joint.

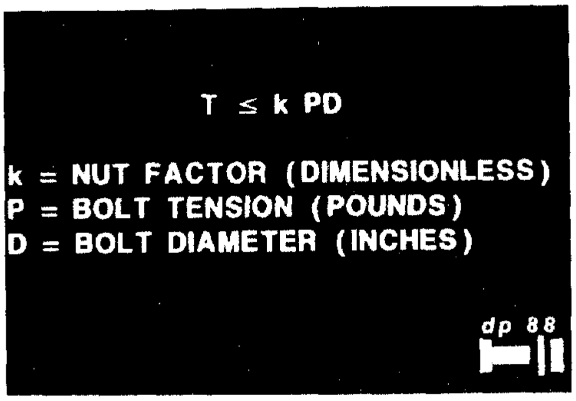
3 - 50

Reporting

The results of all tests (including zinc coating thickness) must be recorded. Locations where tests are performed and date of tests are also recorded.

Witnessing

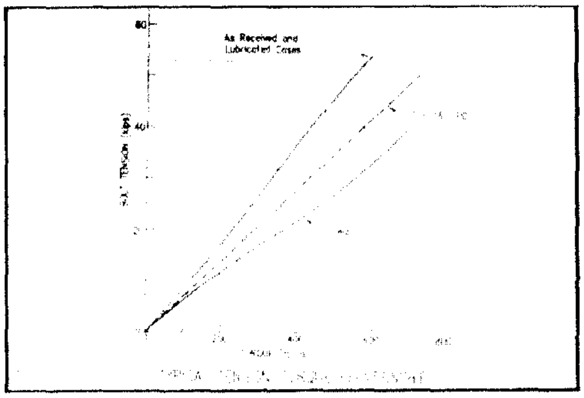
The tests need not be witnessed by an inspection agency, however, the manufacturer or distributor is required to certify that the results are accurate.



3 - 51

INSTALLATION

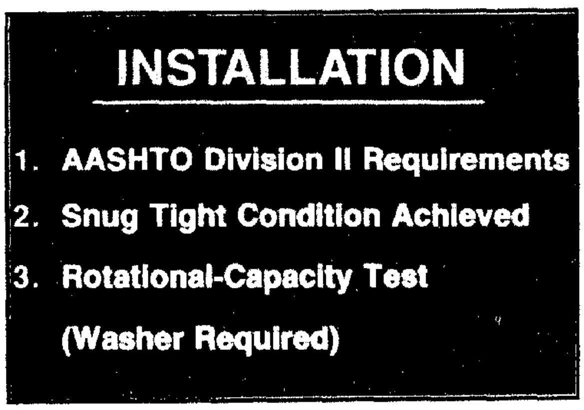
Why are installation test procedures necessary at the job site?



3 - 52

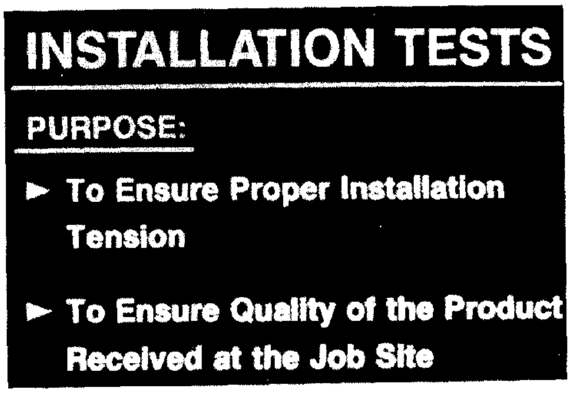
Considering "as received" and clean bolts, it is obvious that there can be a large variation in bolt tension for a given torque. Significant torque variation from what was needed in the laboratory can occur during installation. (-38 to +39% for A325 black bolts and -32 to + 3% for A490 bolts have been reported in the literature.)

Hence, calibration tests should be done in a manner that provides a reliable installation torque for a given lot of bolts.



3 - 53

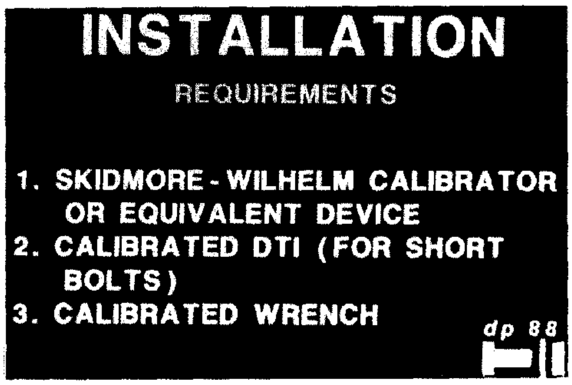
In the field, bolts must be installed in accordance with AASHTO Div. II Art. 10.17.4. Upon verifying the visible lubricant, examining the surface condition of fasteners, and verifying the lot number, the snug tight condition is achieved and the rotational-capacity test is performed similar to the testing by the manufacturer (or supplier) as discussed earlier.



3 - 54

Purpose of Installation Tests

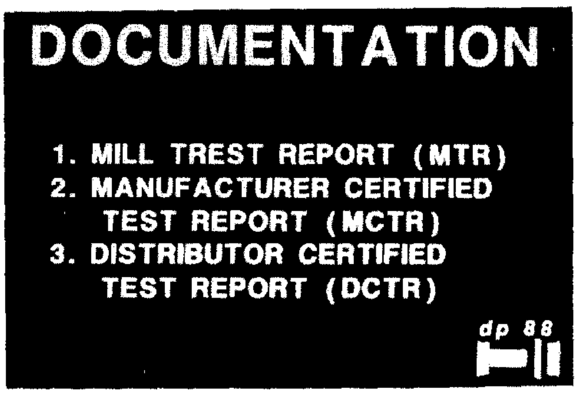
Installation procedure tests are required to ensure proper installation tension as bolts are installed, and also to ensure quality of the product received in the field.



3 - 55

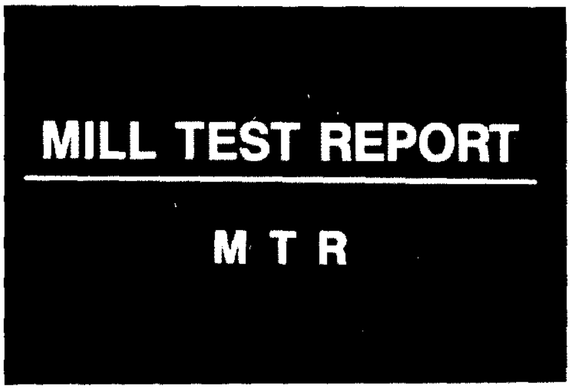
Installation Test Requirements

- 1 - A Skidmore-Wilhelm Calibrator or an acceptance equivalent device.
- 2 - Calibrated direct tension indicating washers (for installation testing for short bolts).
- 3 - Calibration wrench (periodic testing at least once each working day - when calibrated wrenches are used).



3 - 56

DOCUMENTATION



3 - 57

Mill Test Report

A “Mill Test Report” (MTR) must include test results from tests performed on the steels used in the manufacture of fasteners (bolts, nut and washers).

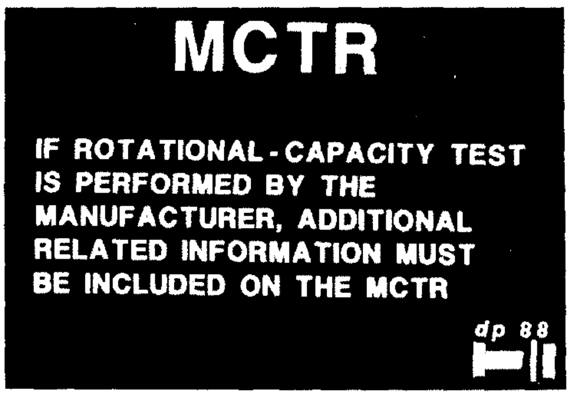
The tests required in the MTR may be performed by the mill or an independent testing agency.

Mill test reports are required to show the name of the country where the material was melted and manufactured.

3 - 58

Manufacturer Certified Test Report(s)

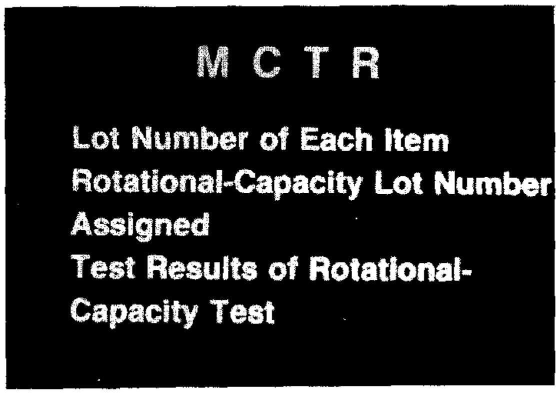
A “Manufacturer Certified Test Report” (MCTR) must include test results for the items furnished (bolts, nut and washers as appropriate) and other relevant information required (e.g., where tests were performed and date of tests, etc.).



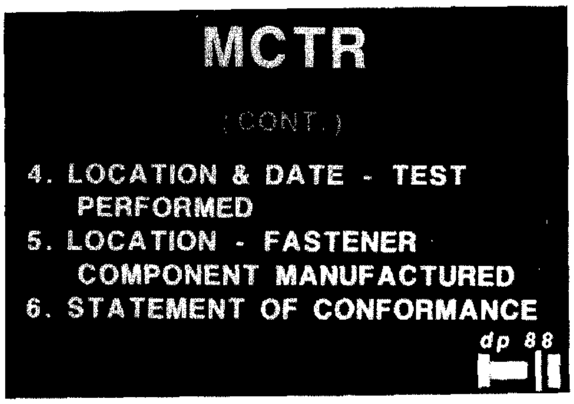
3 - 59

If the manufacturer performs the rotational-capacity test, the MCTR must include the following:

- 1 - The lot number of each item tested.
- 2 - The rotational-capacity lot number assigned.
- 3 - Test results of the rotational-capacity test.
- 4 - Location where tests are performed and date of test.
- 5 - The location where fastener assembly components were manufactured.
- 6 - The statement that items in the MCTR meet appropriate specifications.



3 - 60



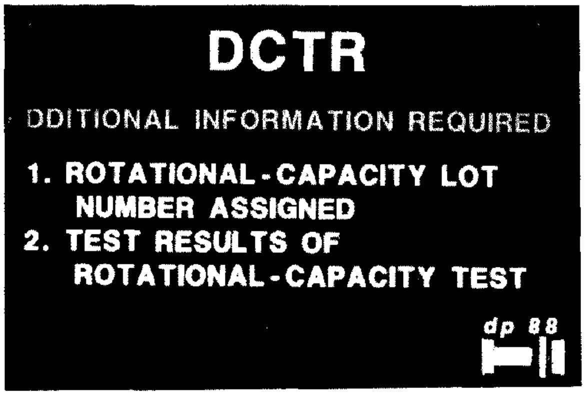
3 - 61

3 - 62

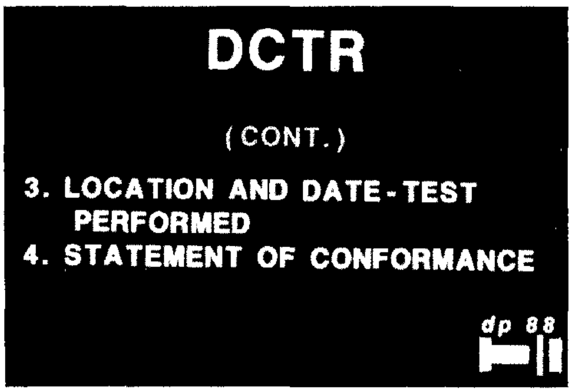
<u>Distributor Certified Test Report(s) DCTR</u>

The distributor certified test report (DCTR) is required to include the MCTR noted above. If the rotational-capacity test is performed by the distributor (or an inspection agency representing the distributor), the results of the test and the following information are to be reported by the distributor:

- 1 - The rotational-capacity lot number assigned.
- 2 - Test results of rotational-capacity test.
- 3 - Location where tests are performed and date of test.
- 4 - The statement that the MCTR is in conformance with appropriate specifications.



3 - 63



3 - 64

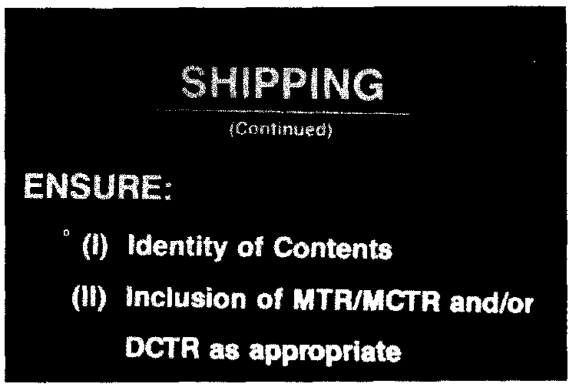
3 - 65

SHIPPING

If there is only one production lot number for each size of nut and washer, they may be shipped in separate containers. Otherwise, components from each rotational-capacity lot are required to be shipped in the same container.

3 - 66

Each container is marked with rotational-capacity lot number and adequately identified.

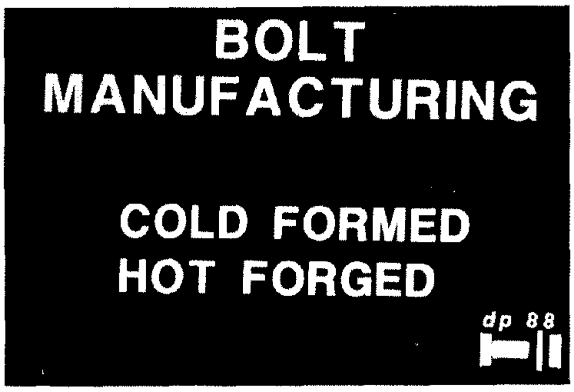


3 - 67

The MTR, MCTR or DCTR is supplied to the contractor or owner as required.

Session 4

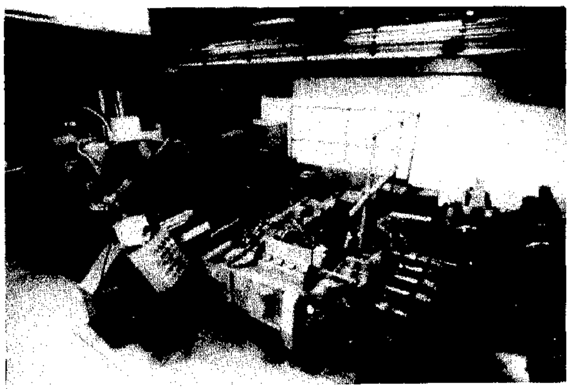
Manufacturing Processes



4 - 1

COLD FORMED FASTENERS

Bolts are manufactured by either cold forming or hot forging methods. Most intermediate diameters (5⁄8 inch through 1 1⁄4 inch) are cold formed.

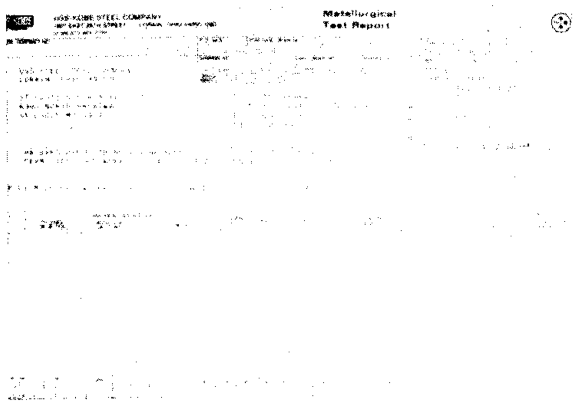


4 - 2

Cold formed bolts are manufactured in a bolt maker, which is a horizontal, multi-station, mechanical press.

4 - 3

Material for cold formed bolts is received from the steel mill in coils. Each coil has a tag attached identifying the mill heat number, material grade or type and chemistry. Depending upon the source, a mill heat would yield 100 coils weighing about 1 ton per coil. The material is hot-rolled and non-annealed.


Metallurgical
Test Report

4 - 4

A mill test report (MTR) is furnished for each heat by the producing mill. This MTR must list the heat number and heat analysis. Additionally, for "Buy American" projects, the MTR will include a statement indicating that the material was melted and manufactured in the U.S.A.

4 - 5

The first step in the manufacture of bolts is to clean the coils. In this operation, called "pickling", the coils are suspended in a sulfuric acid tank. They subsequently receive a water rinse and a heavy lime coating.

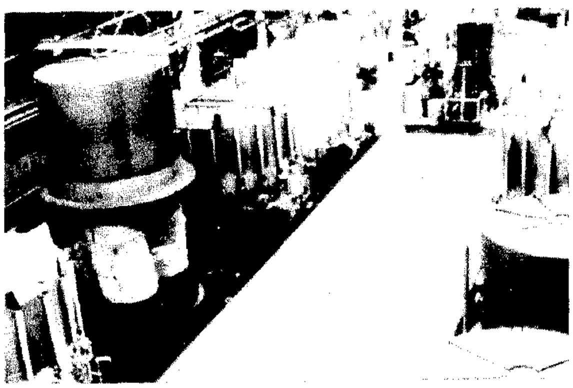
4 - 6

The lime neutralizes the effect of any remaining acid, protects the material from corrosion and acts as a base for lubrication added in a later operation.

Some manufacturers purchase the raw material already pickled and coated. Others abrasive blast the material to remove mill scale and dirt.

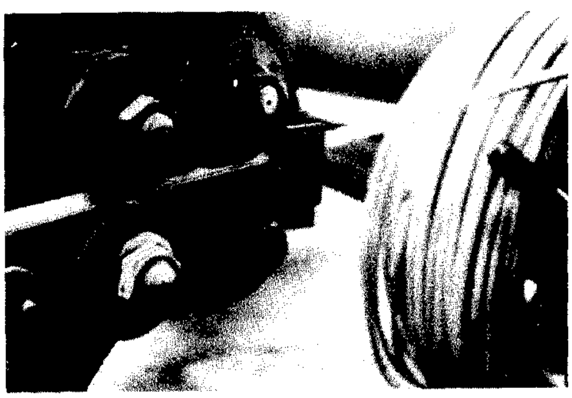
4 - 7

After pickling, additional identification may be used, including color coding and re-tagging.



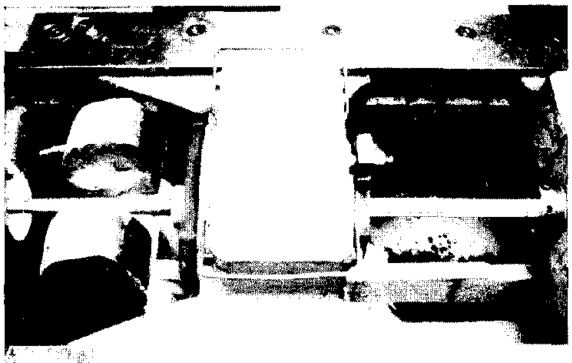
4 - 8

Coils are then annealed. Annealing is a form of heat treatment that softens the steel and increases its ductility and formability. The material is heated in a controlled atmosphere to approximately 1400^{o}F and held for 24 to 48 hours.



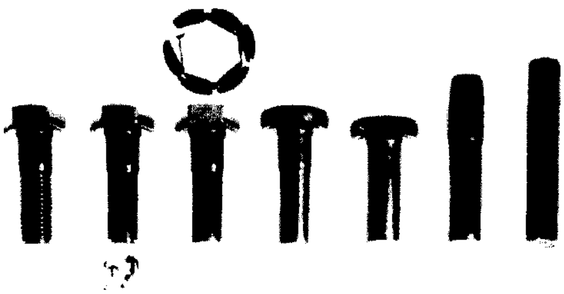
4 - 9

Raw material is then moved to the manufacturing area. Initially, the coil is fed into the wire drawer. The offset rollers straighten the wire and the carbide die reduces the diameter approximately .030 in. to the required shank diameter.



The material to the left of the die is .030 inch or about 1/32 inch smaller in diameter. Some manufacturers purchase material that has been drawn to the finished diameter.

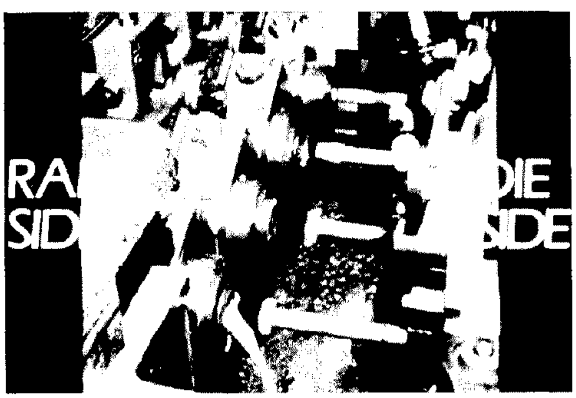
4 - 10



The material then feeds to the bolt maker. The manufacturing stages are:

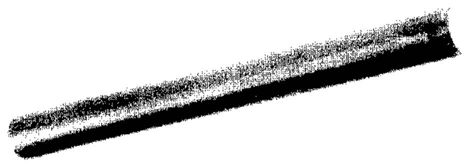
- cut-off, upset, head, extrude, trim, point and roll thread.

4 - 11



The guts of the bolt maker are a series of hydraulic presses. The bolt moves from the far side of the press toward the near side on each stroke of the machine. We can see the various forming stages in the manufacturing operation.

4 - 12

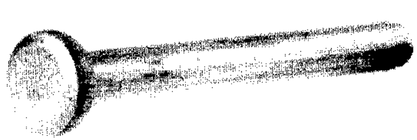


First, a blank of appropriate length is sheared from the coil. Blank length depends on bolt length and head size.

4 - 13

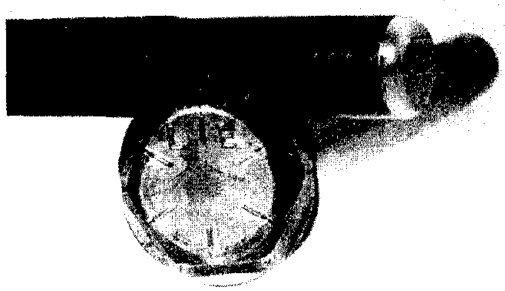
The first station then forms an upset or preform on one end of the blank in preparation for heading.

4 - 14



The second station forms a button from the upset. In this station the washer face, fillet radius, headmark, and head height are also formed. The actual sequence may vary between different manufacturers.

4 - 15

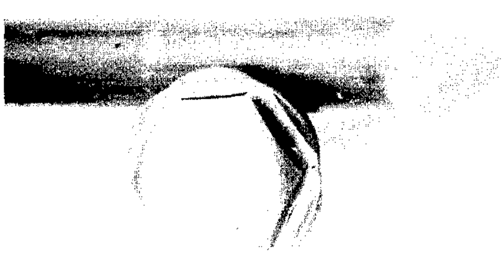


Next, the length of shank to be threaded is extruded to the thread pitch diameter (as shown on the upper bolt). The bolt then moves to the trimming station where a trimming die shears material from the circumference to form the hex shape (the bottom bolt).

4 - 16

Here, the trim drop is separated from the hex head.

4 - 17



The end of the bolt is then chamfered by a set of rotating carbide cutting tools. Not all manufacturers chamfer or point the bolt.

4 - 18

4 - 19

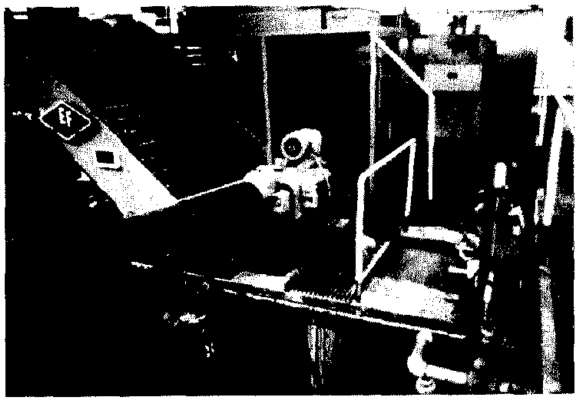
The threads are then rolled by placing the bolt between two thread forming dies. One die moves relative to the other rotating the bolt approximately 3 1/2 turns while forming the threads.

The threaded bolts

4 - 20

4 - 21

Once formed, the bolt must be hardened and tempered to produce the mechanical properties required by the standard. The bolts are fed into a controlled atmosphere furnace, heated to approximately $1600^{o}F$ and held at that temperature for about 45 minutes. This operation alters the bolt microstructure. The material travels through the furnace on a continuous belt.

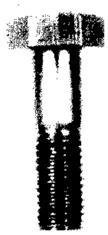


The bolts are then quenched in an oil or water solution. Quenching forces the bolt to cool rapidly, hardening the bolt and changing the microstructure.

4 - 22

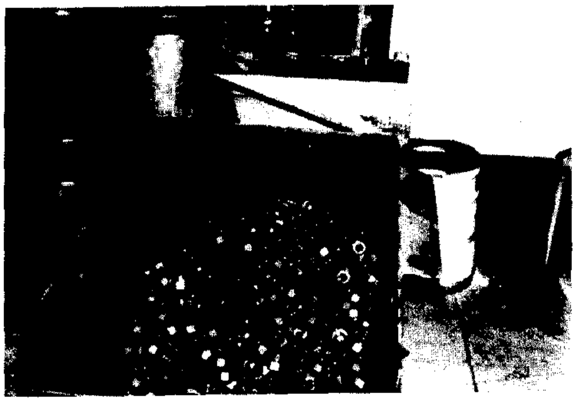
After quenching, the bolts are washed and loaded into the tempering furnace. They are heated to 800°F minimum and held for approximately 45 minutes. Tempering reduces hardness, increases bolt ductility and produces the strength level required by specification.

4 - 23



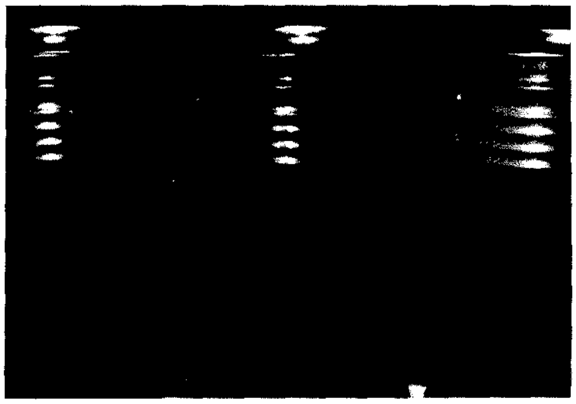
After tempering, the bolts are cooled to about 475°F. They are then drenched, usually in a water soluble oil solution to create the black heat treated finish found on non-coated fasteners. The FHWA Memorandum requires that the finish be "oily".

4 - 24



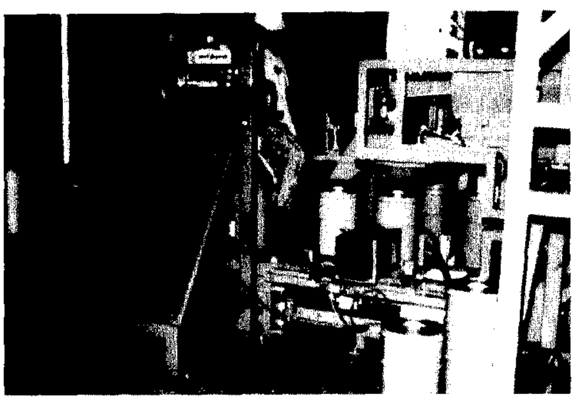
4 - 25

After testing, the bolts are ready for packaging. Some manufacturers package fasteners with the nut assembled to the bolt.



4 - 26

Shipping containers are marked with the necessary information. The container shown in Figure 4-26 does not have the Rotational-Capacity Lot No. shown and would not be acceptable for bridges.

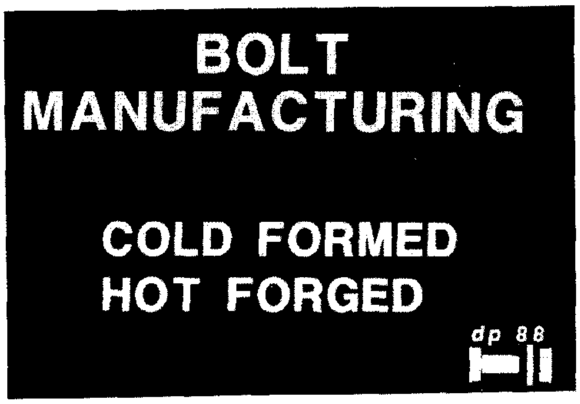


4 -2 7

The containers are then filled.

4 - 28

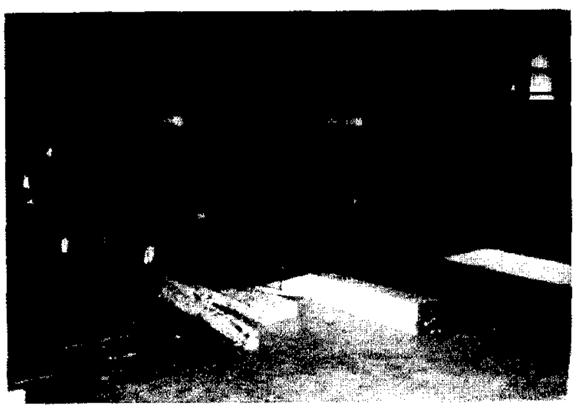
. . . and the pails loaded on pallets for storage or shipment.



4 - 29

HOT FORGED FASTENERS

As noted earlier, bolts are either cold formed or hot forged. The previous discussion demonstrated the cold forming process.



4 - 30

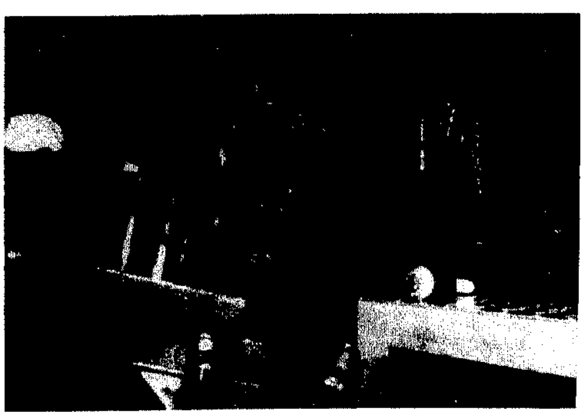
Larger diameter bolts, however, are often hot forged. Material for these bolts is purchased in straight bars to a finished diameter.

4 - 31

The bars are sheared to length and the ends heated to 2000°F for forging.

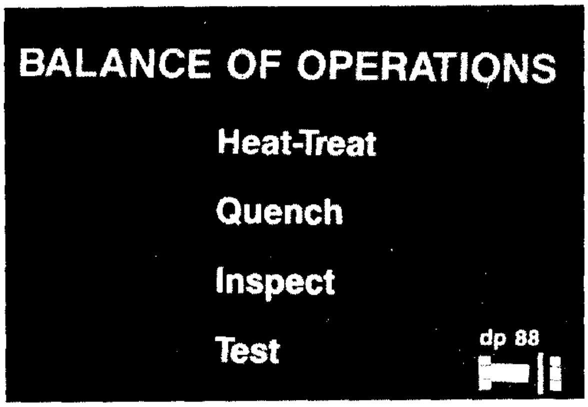
4 - 32

The heads are individually forged by the hot forge operator.



4 - 33

Threads are then either cut or rolled. Here the threads are rolled on a rotary type threading machine. The cylindrical inside forming die rotates with respect to the outside die while forming the threads.



4 - 34

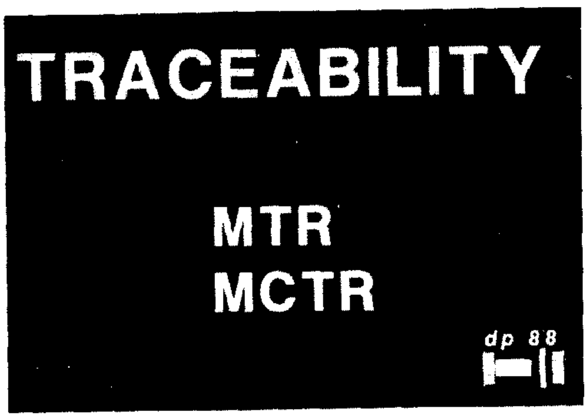
The remaining operations are similar to the cold forming operations, heat-treat, quench, inspect and test.

4 - 35

<u>QUALITY CONTROL</u>

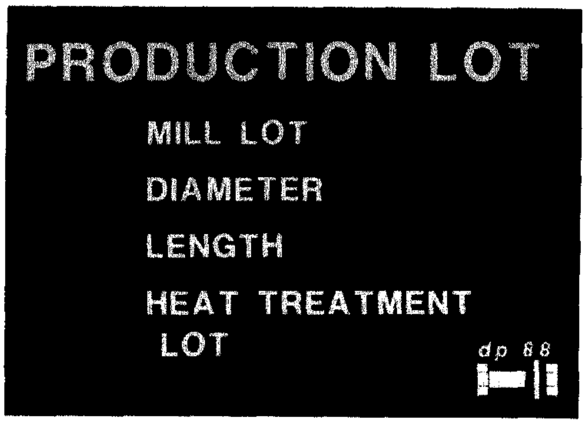
Quality control is an essential function in all bolt manufacturing operations. Quality control consists of:

- Material traceability through various operations.
- In process testing to verify process control.
- Product testing and inspection to verify conformance to standards.
- Reporting results on the Manufacturers Certified Test Report (MCTR).



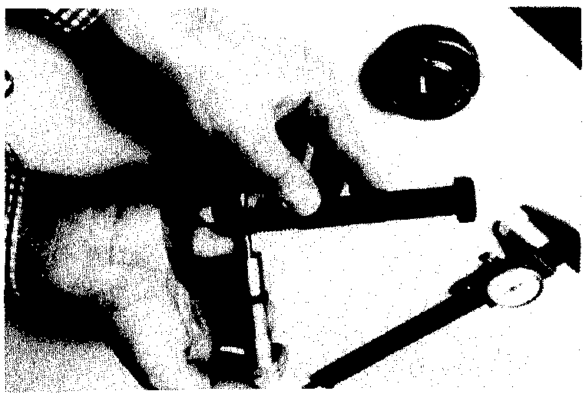
4 - 36

Traceability from the mill material through all operations to the bolts in the shipping container is required. The original Mill Test Report (tied to the heat number) and the Manufacturers Certified Test Report (tied to the production lot number) provide the record.



4 - 37

A production lot number ties it all together. Unique lot numbers are assigned for each combination of mill lot, bolt diameter, bolt length and heat-treatment lot. A typical production lot could contain as many as 30,000 pieces.



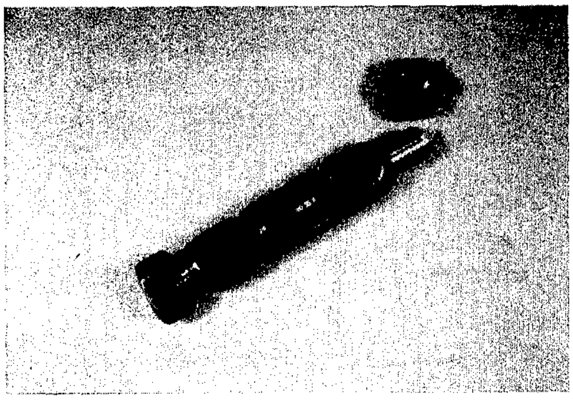
4 - 38

In process control is applied at various stages of the production cycle. Periodically dimensions and tolerances are checked for conformance to standards.

The outside diameter is checked with a micrometer.

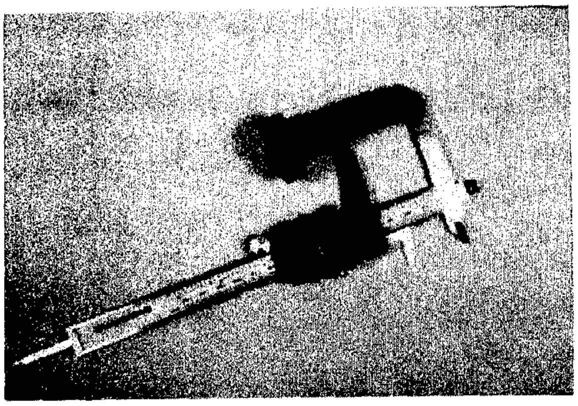
4 - 39

Bolt threads are checked with a ring gage.



4 - 40

Nut threads are checked with a go/no-go gage.



4 - 41

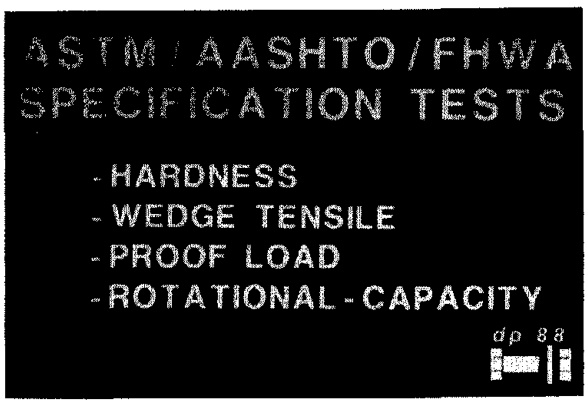
Thread lengths are checked.

4 - 42

In-process hardness tests are performed at regular intervals.

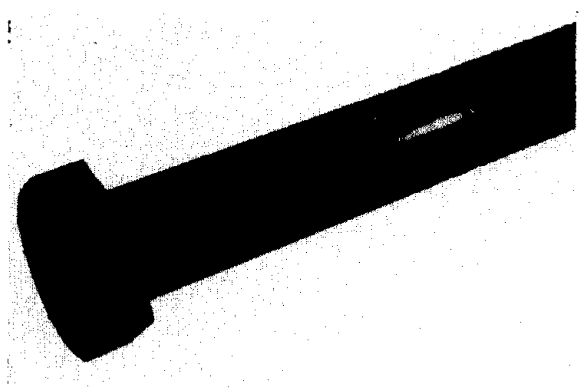
4 - 43

In-process magnetic particle inspection may be performed for discontinuities. For A490 bolts, magnetic particle inspection is required. The bolts are magnetized, covered with a special magnetic solution, and viewed under a black light. Defects such as cracks and seams will show up as a vivid yellow line.



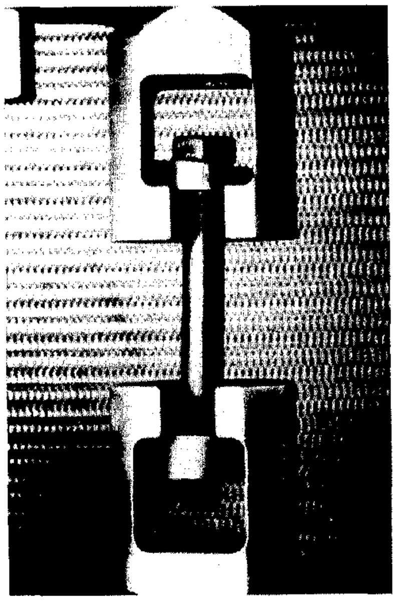
4 - 44

Samples from each production lot are tested in accordance with appropriate ASTM, AASHTO or FHWA requirements. Results of all tests are recorded on the Manufacturers Certified Test Report (MCTR). Typical tests include hardness tests, wedge tensile tests, proof load tests and rotational capacity test.



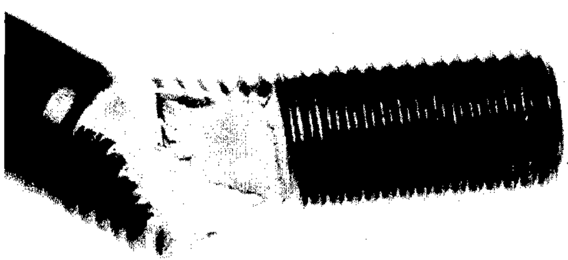
4 - 45

Typical hardness tests may be made on ends, wrench flats or unthreaded shanks.



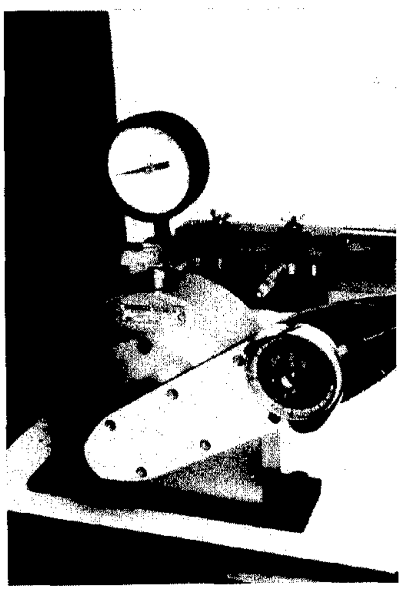
4 - 46

Wedge tension tests demonstrate bolt strength, ductility, and integrity of the head/shank junction. The tapered wedge adds significantly to the severity of the test.



4 - 47

Wedge tension test failure must occur in the body or threaded section of the bolt. It may not occur at the head/shank junction, in spite of local bending due to the tapered wedge.



4 - 48

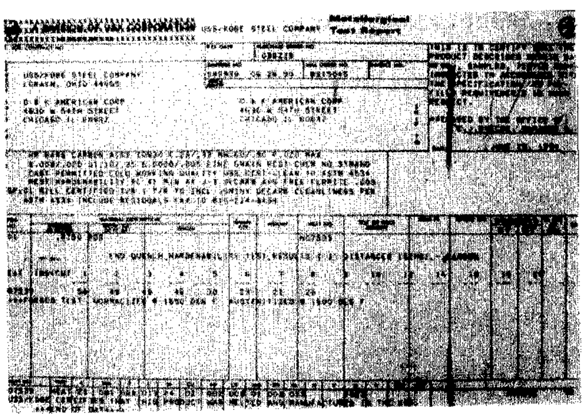
Rotational capacity tests demonstrate the presence and efficiency of lubricant, functional thread fit between the nut and bolt, and the assembly's capability to be preloaded.

A rotational capacity lot number is assigned to the bolt/nut combination after the rotational capacity test has been performed. Bolts and nuts that have been tested may then be shipped together in the same container. When nuts and washers are from singular production lots, they may be packaged separately, provided each R-C lot number is identified on the container.

4 - 49

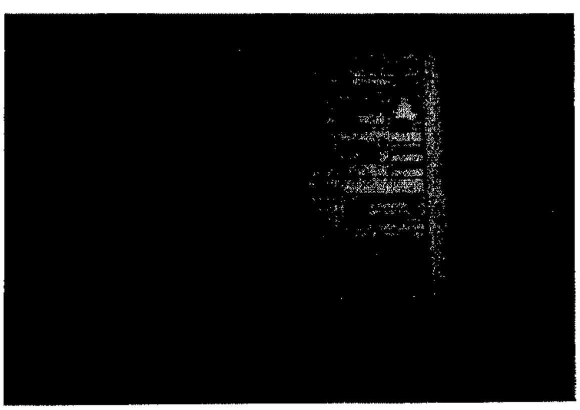
Results of all tests are recorded or reported on various forms:

- Mill Test Report (MTR)
- In Process Records or
- Manufacturers Certified Test Report (MCTR)



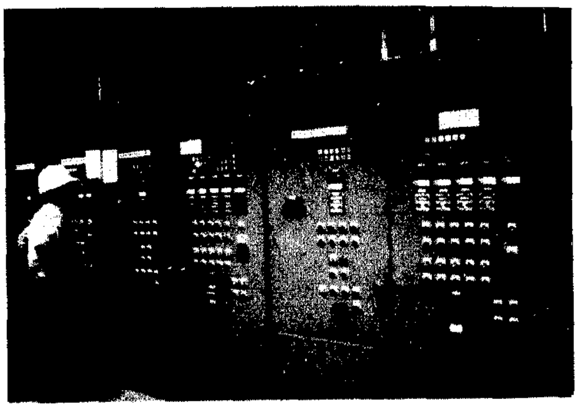
4 - 50

The Mill Test Report is furnished by the mill supplier. It contains records of mill heat number and chemical test results.



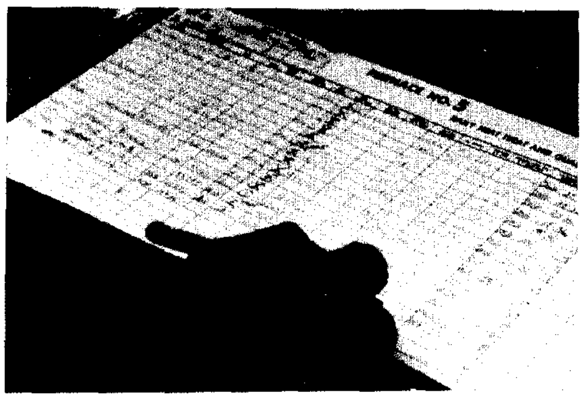
4 - 51

In-process records include the results of in process tests.



Continuous record of furnace temperature.

4 - 52

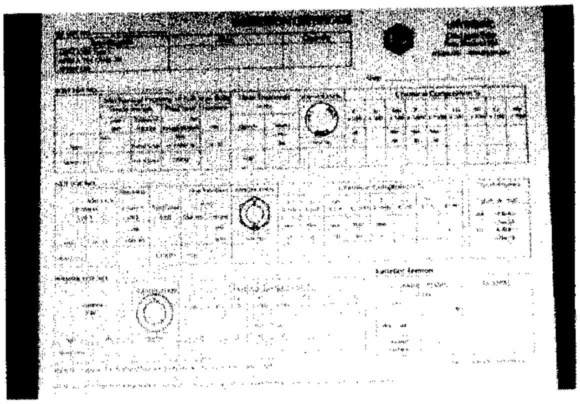


Test results and furnace loadings.

4 - 53

Heat Treatment Log.

4 - 54



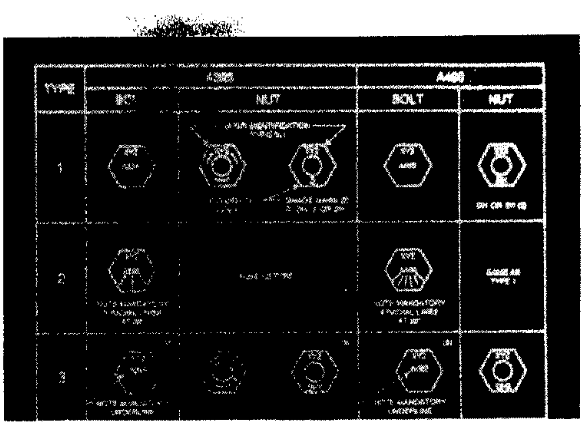
4 - 55

The Manufacturer Certified Test Report (MCTR) contains the balance of all information, including the results of all tests required by the pertinent specification. Documents (MTR & MCTR) are delivered to the customer with the shipping container or by mail, depending on customer requirements.

4 - 56

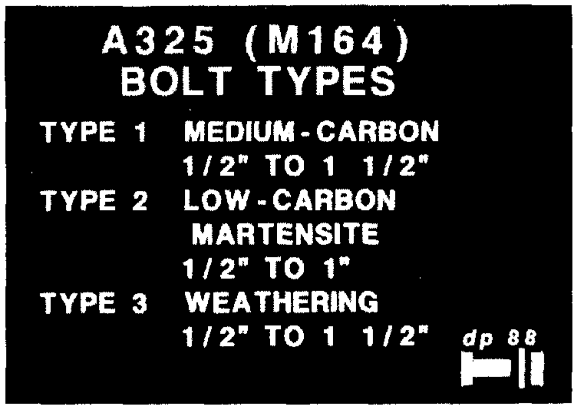
PRODUCT MARKING

The ASTM Specifications require that all parts of the fastener assembly be distinctively marked. The marking operation is an integral part of the forming or forging procedure. Marks may be either raised or depressed, depending on the product. If nuts are marked on the bearing face, the marks shall be depressed.



4 - 57

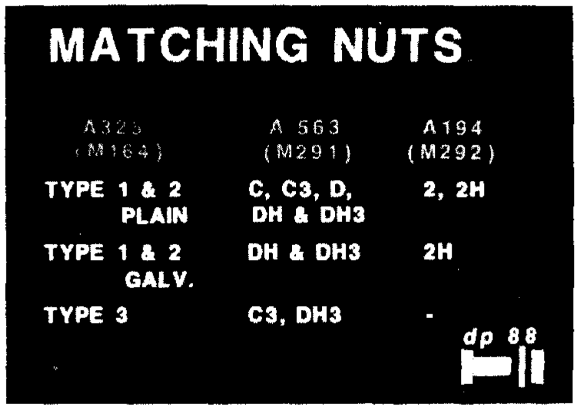
Certain markings are mandatory, while others are optional. The commentary to the RCSC Bolt Specification shows these in more detail. Marking with a symbol identifying the manufacturer is mandatory. The appendix contains a document, IFI-I22, that identifies the various manufacturers' symbols.



4 - 58

FASTENER TYPES

The A325 specification allows for the manufacture of bolts from three different types of material. Type 2 material has been a problem and domestic manufacturers no longer use it. The 1991 ASTM specification will probably eliminate that grade. Type 1 bolts are those that are used in most typical installations. Type 3 bolts are corrosion resistant for use in unpainted A588 structures. They may, however, be used in lieu of type 1 bolts.

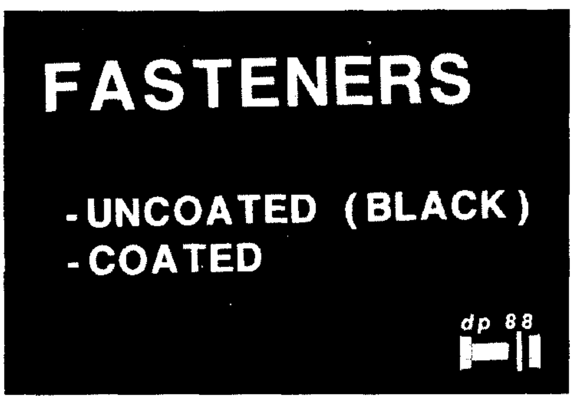


4 - 59

Nuts are manufactured to at least 7 different grades from 2 different specifications. The two specifications are A563 and A194.

Matching nuts for A325 bolts include non-heat- treated grades 2, C, C3, and D, plus heat-treated grades 2H, DH and DH3. The FHWA Supple- mental Specification requires that grades 2, C, C3 and D meet special minimum hardness requirements when used for bridges.

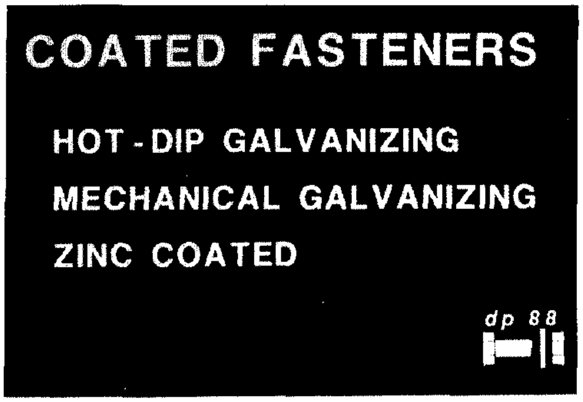
Galvanized nuts must be heat-treated grades 2H, DH or DH3.



4 - 60

COATED FASTENERS

Additional processing, such as coating the bolts, may be performed by the manufacturer or the subcontractor. A325 fasteners may be either coated or uncoated (black). The purchaser must specify the type of fastener required. Normally, the coating used for coated fasteners is zinc.



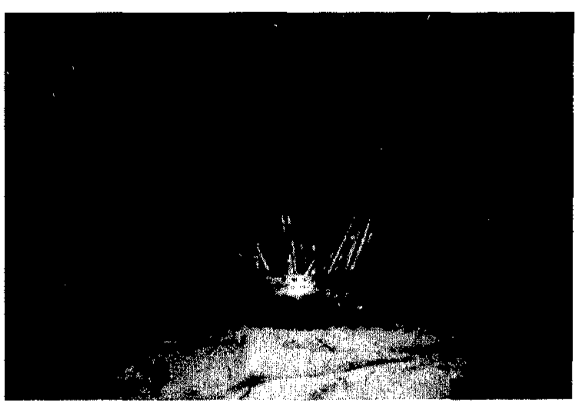
4 - 61

The A325 specification specifically refers to two processes for zinc coated fasteners, hot-dip and mechanically galvanized. Other methods of applying the zinc coatings are available.

4 - 62

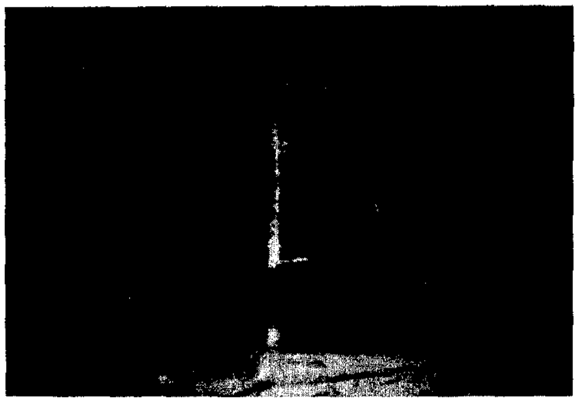
The hot-dip galvanizing process comprises a four step procedure:

- Clean
- Immerse in molten zinc
- Spin to remove excess zinc
- Quench to harden the zinc



4 - 63

After cleaning in a pickling bath, the material is dipped in molten zinc. The temperature of the molten zinc is 850°F. Bolts typically remain in the molten zinc for 5 to 10 minutes, depending on the weight of material in the bucket.

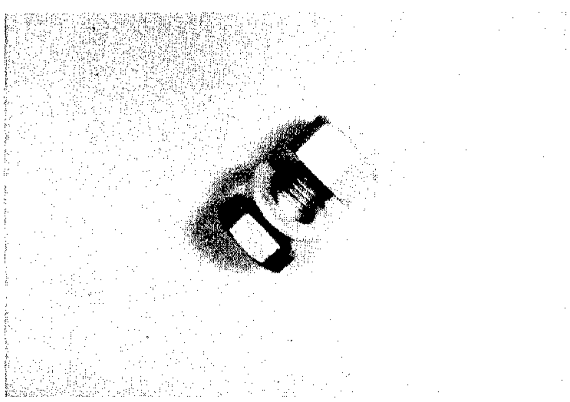


4 - 64

Upon removal from the molten zinc, the material is spun in an enclosed kettle to remove excess zinc from the threads.

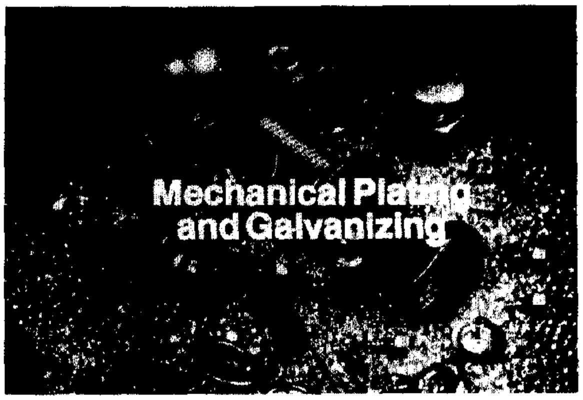
4 - 65

After spinning, the product is dumped into a water quench tank to complete the process.



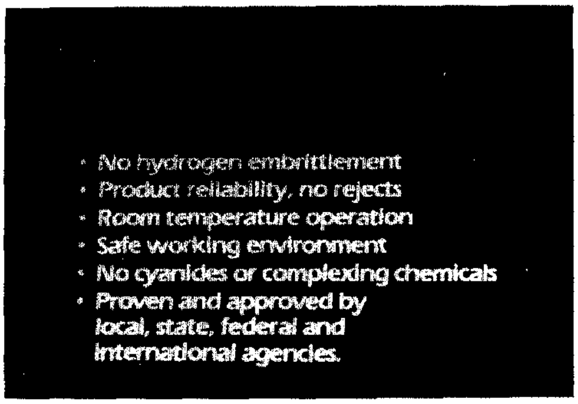
4 - 66

The process is now complete.



4 - 67

Another popular method of coating bolts is the mechanical galvanizing process. Mechanical galvanizing is a cold process where the coating is applied by an impacting process. Proprietary chemicals, glass impact media, and metal powders are rotated in an open barrel along with parts to be coated.



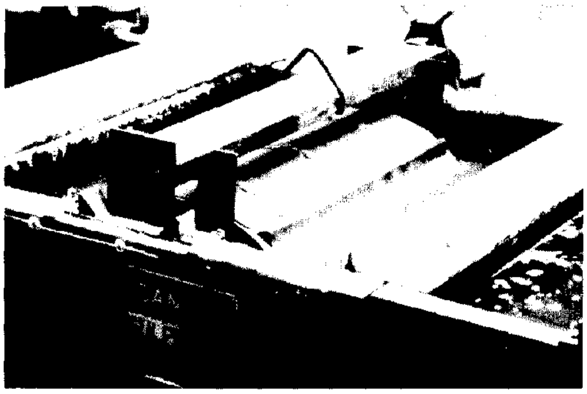
4 - 68

Process advantages include low hydrogen embrittlement possibilities, low energy usage, and simplified disposal of waste products.

4 - 69

Most of the work takes place in this rubber-lined barrel. The process includes:

- Soil or scale removal
- Surface preparation
- Plating
- Separation and drying

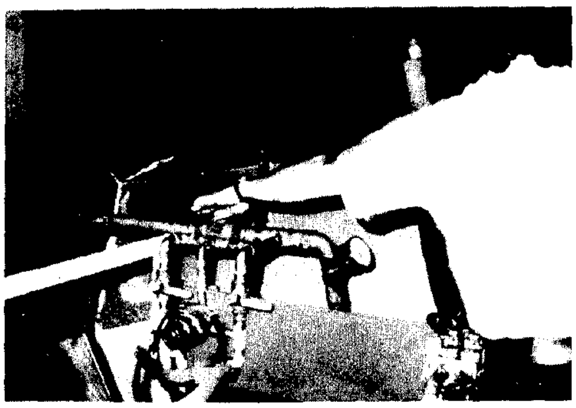


4 - 70

Parts are first cleaned in a sulfuric acid bath. They are then loaded into the barrel.

4 - 71

The impact medium of glass beads is added.



4 - 72

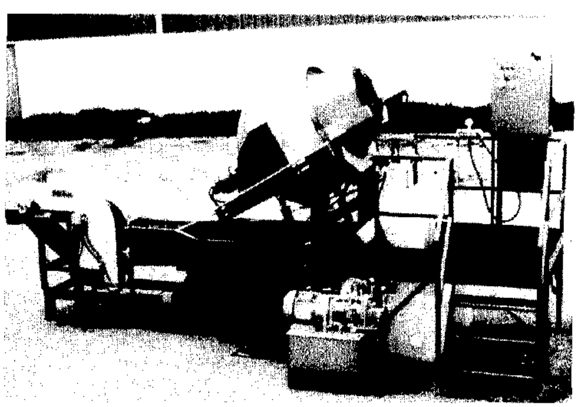
Tempered water is added.

4 - 73

Surface conditioners are then added to the rotating barrel where the cleaning and surface preparation take place.

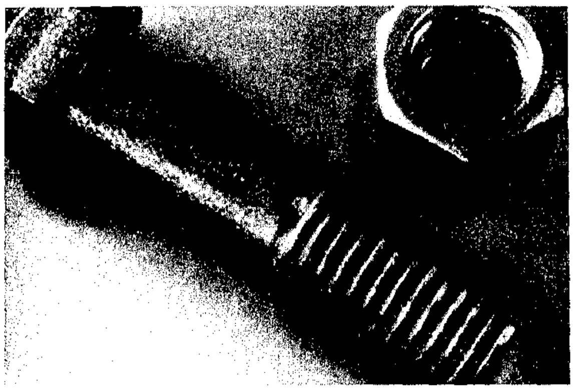
4 - 74

The zinc powder is then added. The zinc particles are cold welded onto the parts by the many impingements of the small glass beads under pressure from the overlying parts.



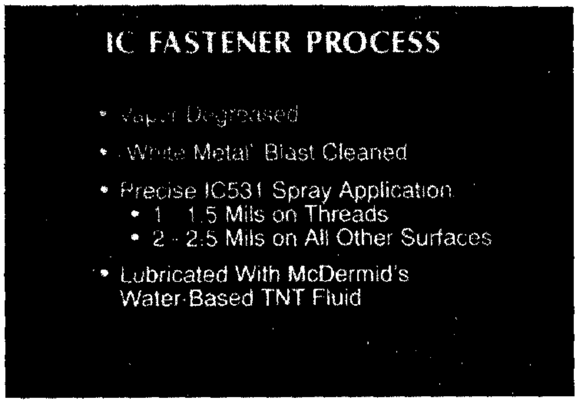
4 - 75

The main component is the rubber lined rotating barrel with sizes ranging from 1 to 30 cubic feet. After plating, the mixture of parts and media are dumped into a hopper. The hopper then dumps the material on a vibrating screen or magnetic belt, allowing the media and plated bolts to separate. The bolts are then dried and the media, after some treatment, is reused.



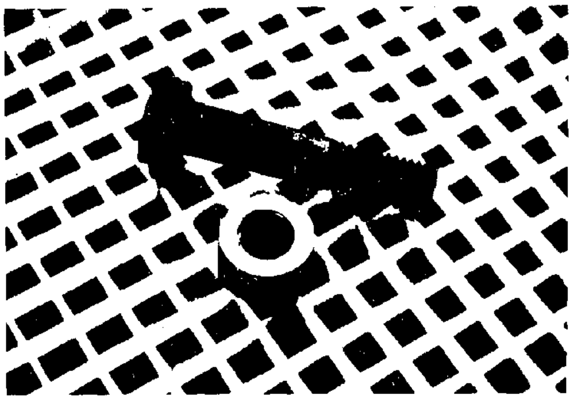
4 - 76

This is the mechanically galvanized product.



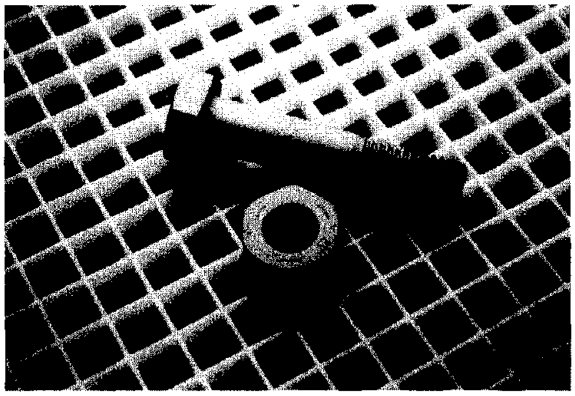
4 - 77

A third type of coated bolt is the spray coated fastener. In this procedure the fastener is cleaned, abrasive blasted, spray coated and lubricated.



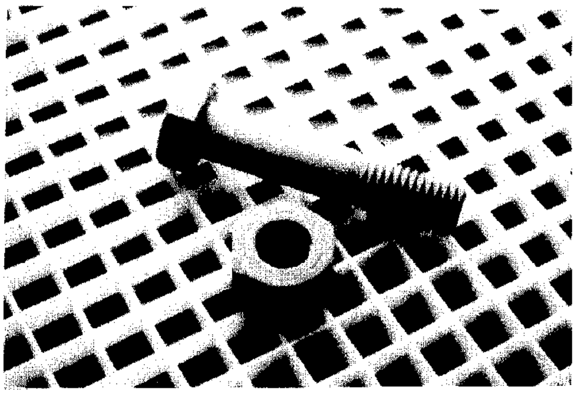
4 - 78

The product is degreased in a three-step process.



4 - 79

The fastener is then blasted to a "white metal" specification using a fine grit.



4 - 80

It is then coated with a high-ratio zinc silicate and lubricated.

Obviously, there is much more that can be presented relative to fastener manufacturing processes. Twist-off bolts, nuts, washers and DTIs have not been addressed. The foregoing, however, should at least provide some insight into the number and complexity of the manufacturing operations involved as well as the quality controls required to produce a specification-conforming product.

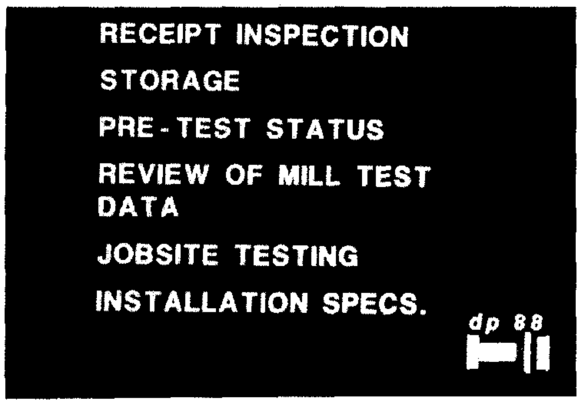
Session 5

Receipt Inspection, Storage, Pretest, Review of MTD

5 - 1

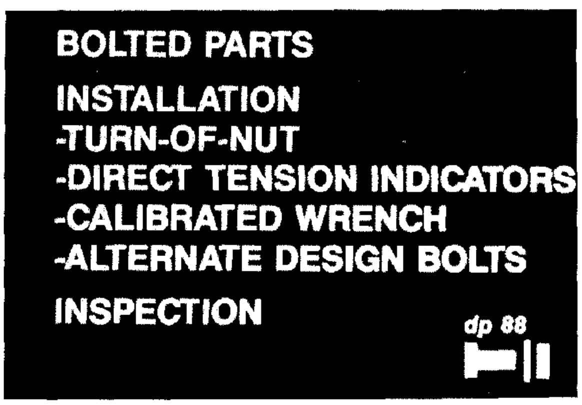
RECEIPT INSPECTION

This session describes specification requirements and inspector responsibilities for job site operations. Material is also applicable to fabrication shop bolting operations.



5 - 2

The areas shown in Slide 5-2 are to be discussed in this section of the course.

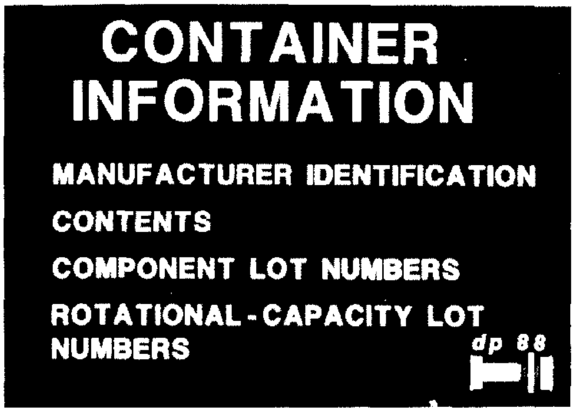


5 - 3

Addional topics are shown in Slide 5-3.

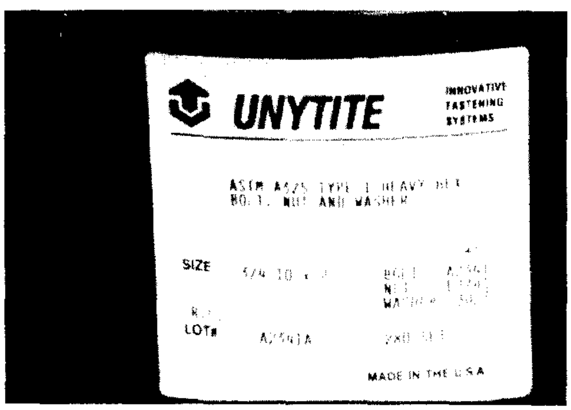
5 - 4

When properly performed, receipt inspection can help to eliminate future installation problems.



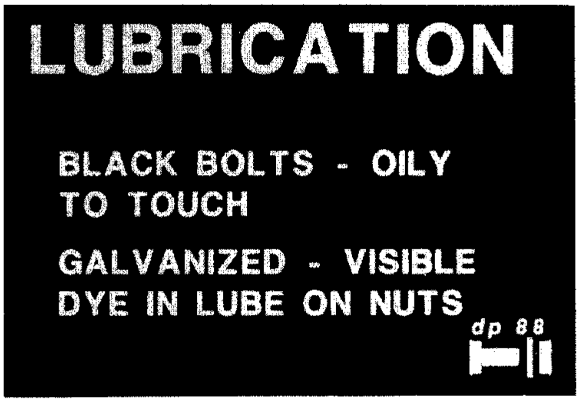
5 - 5

Inspect containers for the information shown in Slide 5-5. Record data for comparison to test reports.



5 - 6

All previously mentioned data must be easily recognizable and permanently marked. Bolts, nuts and washers must be in the same shipping container, except where there is only one production lot number for each size of nut and washer. Watch for shipping damage and possible contamination.



5 - 7

Black bolts must be oily to the touch. For galvanized fasteners, the nuts must be lubricated with a material that is clean and dry to the touch, and must contain a visible dye for easy identification.

5 - 8

STORAGE

Fasteners must be protected from dirt and moisture at all times. Lubricant on black fasteners will hold dust. Cover to protect from rain, snow or dew. Plastic sheeting over containers and sealed to ground will cause fasteners to sweat. Provide adequate ventilation.

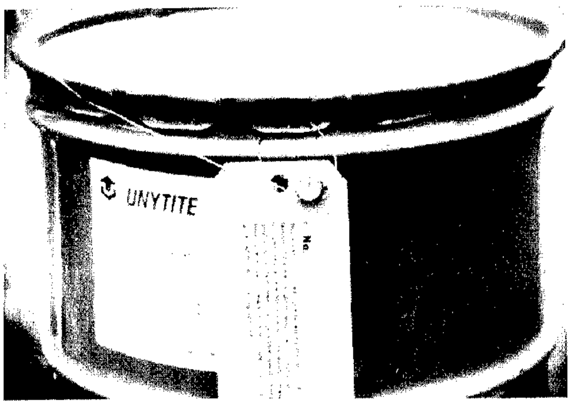
5 - 9

Keep away from grease or oil. Store all fasteners in original containers and return unused fasteners to maintain lot identification. Remove only enough fasteners for use on one work shift.

5 - 10

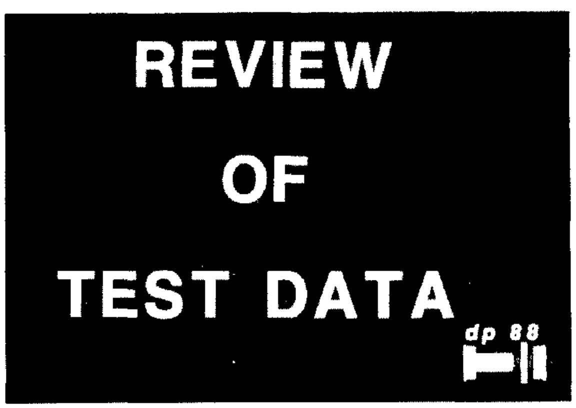
PRE-TESTING

Many State DOTs have procedures which require tests to be conducted at the producer's plant and witnessed by a DOT inspector or consultant inspector. Others sample material at the plant and conduct tests in the DOT laboratory.



5 - 11

Where this is done, most DOTs identify containers with a tag or stamp to show project site inspectors that the fasteners have been approved for use. Inspectors on project site or in the fabrication shop must be aware of appropriate QA system used by DOT and verify materials are approved.



5 - 12

REVIEW OF TEST DATA AND REPORTS

In many cases, fasteners are not inspected at their source, and the job site or fabrication shop inspector must review test data and decide if the fasteners are acceptable. This portion of the course will review the documents necessary for ensuring the quality of nuts, washers, and bolts.

"DOCUMENT"

OR

"TEST REPORT"

dp 88

5 - 13

The results of all tests are to be recorded on the appropriate document. Selection of the format is up to the manufacturer and customer (DOT). The document must identify the location and the date of the test. Tests need not be witnessed by an inspection agency. The manufacturer or distributor that performs the tests shall certify that results are accurate.

- Mill Test Report (MTR)
- Manufacturer Certified Test Report (MCTR)
- Distributor Certified Test Report (DCTR)

5 - 14

FHWA Supplemental Contract Specs. make reference to three types of test reports.

We will discuss each in detail and outline their uses and test data requirements.

MILL TEST REPORT (MTR)

STEEL MANUFACTURER
RAW MATERIAL
CHEMISTRY ONLY

dp 88

5 - 15

A mill test report is prepared by the steel manufacturer to document properties of mill steel used to manufacture bolts, nuts and washers. Material may be purchased by the fastener manufacturer to chemistry only to allow for proper heat treating of component. The MTR can be used to verify specification compliance for chemistry only, as all other tests are required on the finished product.

MTR CONTENT

STEEL PRODUCER'S FORM
HEAT NUMBER
CHEMICAL ANALYSIS
LOCATION-MELT & MADE
LOCATION-TESTS CONDUCTED
DATE OF TESTS

dp 88

5 - 16

MTRs must be from the steel producer, on the test report, not copied onto the fastener manufacturer's test report. The MTR must document heat number, analysis, place where steel was melted and manufactured, location where the tests were performed and date of the tests. "Place where steel melted" may note "country only," but, city and state location are recommended. When Type 3 (weathering steel) components are specified, the MTR shall identify to which class (composition) the steel was manufactured. Explain.

MANUFACTURER CERTIFIED TEST REPORT (MCTR)

PREPARED BY BOLT, NUT OR WASHER MANUFACTURER TO DOCUMENT PHYSICAL TEST RESULTS PERFORMED ON FINISHED PRODUCT.

dp 88

5 - 17

The Manufacturer Certified Test Report is prepared by the bolt, nut or washer manufacturer to document the results of physical tests performed by the manufacturer.

MCTR CONTENT

MILL HEAT NUMBERS
FASTENER MANUFACTURER LOT NUMBERS
MULTIPLE TEST RESULTS DEPENDING UPON QUANTITY

dp 88

5 - 18

The MCTR must document the heat number of the steel used to manufacture the product so that traceability is provided back to the MTR. The lot number assigned by the fastener manufacturer must be shown. AASHTO material specifications may require several physical tests of each component, depending upon quantity of each lot number. The MCTR must document all tests required.

BOLT TESTS

PROOF LOAD - METHOD 1

TENSILE TEST - WEDGE

SHORT BOLTS - HARDNESS ONLY

5 - 19

Proof load (Length Measurement Method, ASTM F606 Method 1) tests are required. Method 2 (Yield Strength) or Method 3 (Uniform Hardness) are not acceptable. Wedge tensile tests are required on all bolts long enough for tensile tests. Hardness tests are required for all bolts, and are in lieu of tensile tests for bolts less than 3 diameters long.

BOLT TESTS

(CONT.)

TENSION TEST OVERRIDES LOW HARDNESS RESULT

5 - 20

For bolts on which hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence over low readings on hardness tests.

GALVANIZED BOLT TESTS

ALL MECHANICAL TESTS AFTER GALV.

GALV. THICKNESS TESTS BY BOLT MANUFACTURER

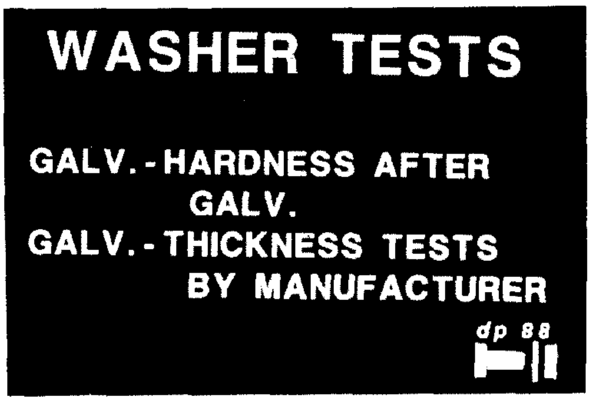
ROTATIONAL - CAPACITY TESTS

5 - 21

When bolts are galvanized, all mechanical tests must be done after galvanizing. Coating thickness measurements must be made by the bolt manufacturer and reported on the MCTR. Rotational Capacity tests required by AASHTO M164 (ASTM A325) are to be conducted and reported by the bolt manufacturer. These tests are not to be superseded by R-C tests as described later in this course.

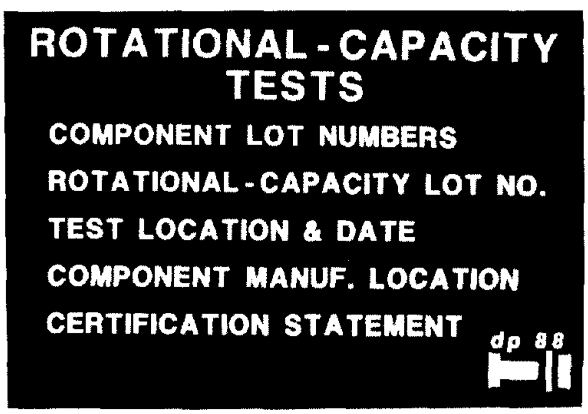
5 - 22

Proof load tests (ASTM F606 paragraph 4.2) are mandatory for all nut sizes and grades. If nuts are galvanized, tests must be conducted after galvanizing, overtapping, and lubricating. The coating thickness must be verified by the nut or bolt manufacturer and reported on the MCTR.



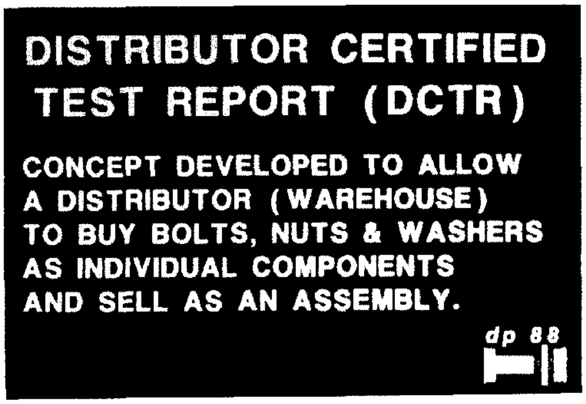
5 - 23

If the washer is galvanized, hardness tests must be made after galvanizing. Coating thickness must be verified by the washer or bolt manufacturer and reported on the MCTR.



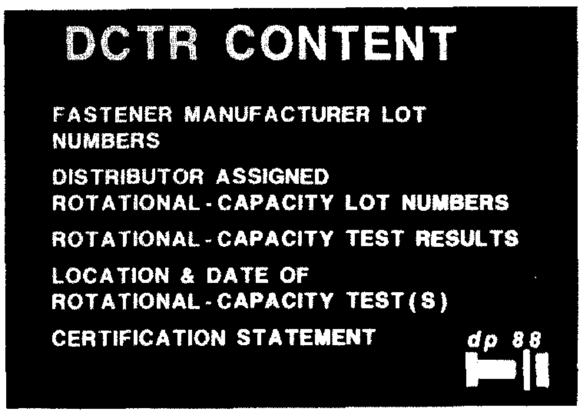
5 - 24

When R-C tests are conducted by the component manufacturer, test results must show on the MCTR. Lot numbers for each component and resulting R-C lot must be documented. The test frequency is two tests per R-C lot. The MCTR must document the location and date of the R-C tests as well as the location where the assembly components were manufactured. The MCTR must contain a certification statement that MCTRs for component materials conform with FHWA specifications and AASHTO specifications.



5 - 25

The Distributor Certified Test Report is prepared by the fastener distributor to document R-C tests and R-C lot numbers. All components must be lot identified on all containers. MCTRs and MTRs must be supplied for all components.

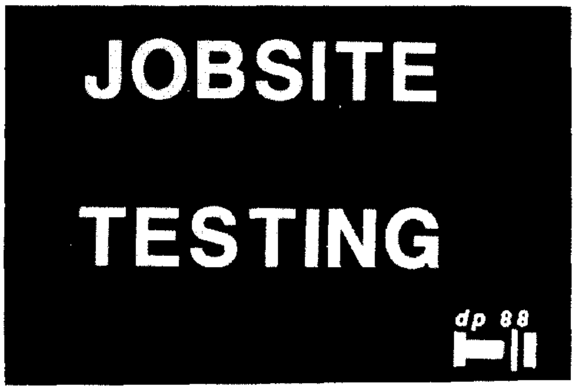


5 - 26

All component lot numbers must be documented, including the R-C lot. The test frequency is two assemblies per R-C lot. The DCTR must document location and date of test. The DCTR must contain a certification statement that the MCTRs for all component items conform with FHWA and appropriate AASHTO material specifications. If the distributor has components galvanized from stock, all physical tests must be re-conducted at proper frequency and reported on the DCTR. The coating thickness must be verified by the distributor.

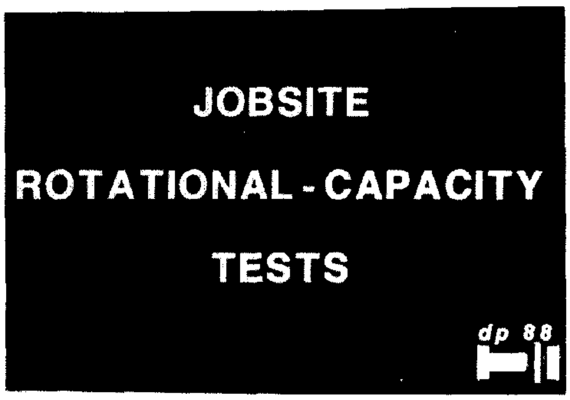
Session 6

Jobsite Rotational-Capacity Testing



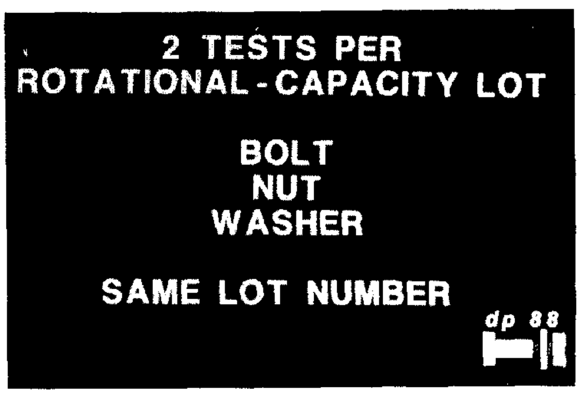
6 - 1

Now that the fasteners are on the job site or fabrication shop floor, have been inspected, and are stored properly with MTRs, MCTRs, and DCTRs reviewed and accepted, the contractor now wants to install them . What tests, if any, must be performed?



6 - 2

FHWA specifications require the R-C test to also be conducted on the project site or at the point where installation takes place. The test should be performed immediately prior to starting installation so that the test will judge the effects of shipment and storage on fastener lubrication. The tests are to be as per AASHTO M164 except as modified by FHWA specifications.



6 - 3

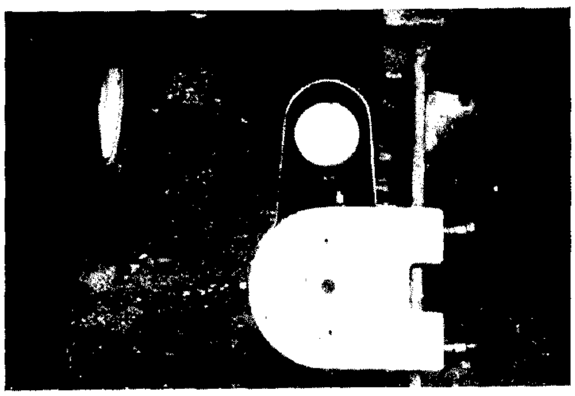
R-C tests must be performed at the rate of two tests per R-C lot as shown on shipping containers. The bolt, nut and washer must have the same R-C lot number and be packed in the same container (except in special cases where nuts and washers have only one production lot number for each size).

6 - 4

Washers are required for the R-C tests even though they may not be required for job-site installation. Where washers are not required for job-site installation, lot identification (both manufacturer and R-C) is not required. Washer coating should be the same as in the bolt and nut. All R-C tests are to be performed by the contractor/fabricator and should be witnessed by the DOT inspector.

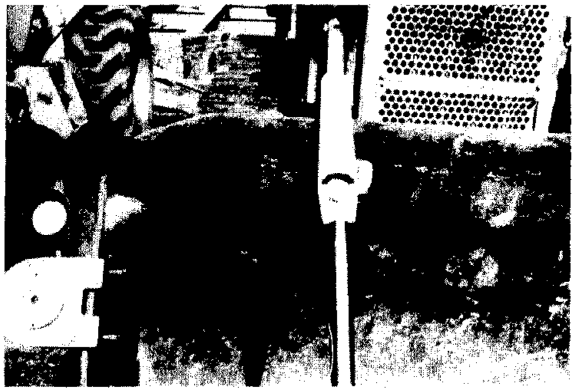
6 - 5

Equipment required to conduct R-C test is as follows.



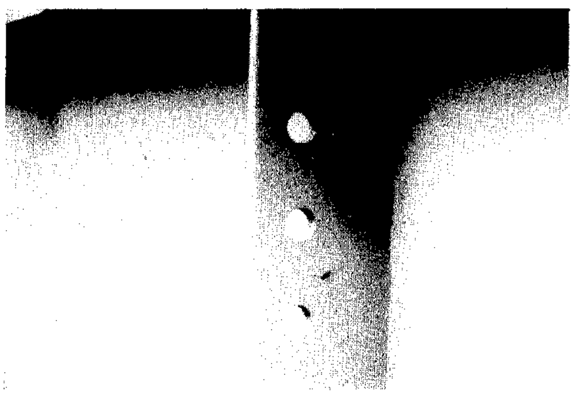
6 - 6

Skidmore-Wilhelm Bolt Tension Calibrator or equivalent tension measuring device. Calibration within the last year.



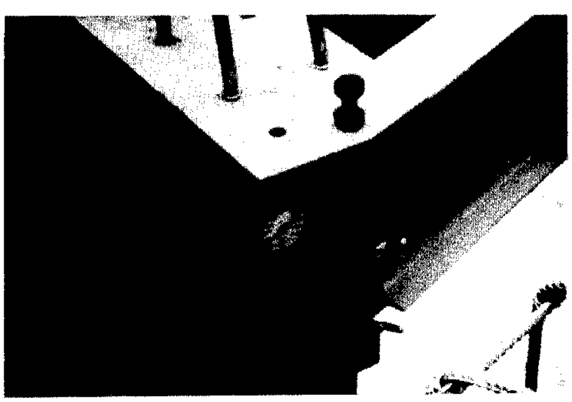
6 - 7

Standard torque wrench. Calibration within the last year. 1000 ft-lb capacity will cover most bridge situations. May require 2000 ft-lb. wrench for 1¼ inch-diameter bolts and larger or a torque multiplication device may be used.



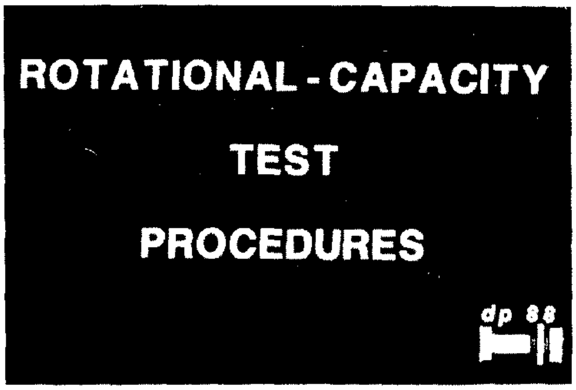
6 - 8

Suitable steel joint to conduct tests on short bolts. The plate thickness is governed by bolt length. Plate can be ½ inch to 1 inch and use shims to adjust for bolt length. The hole size in the plate is 1⁄16 inch over bolt diameter.



6 - 9

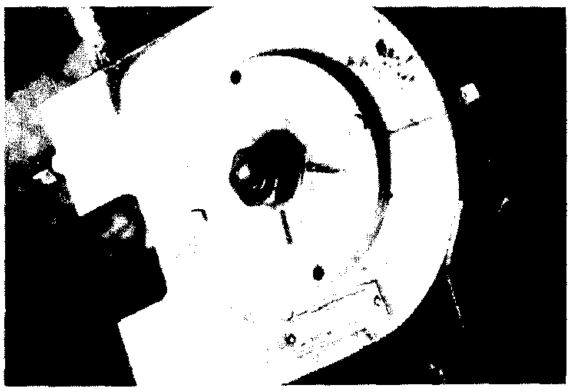
The bolt tension calibrator and steel joint must have rigid mounting as larger-diameter bolts generate extremely high torque numbers.



6 - 10

The R-C test is to be in accordance with AASHTO M164 paragraph 6.5 as modified by the FHWA specification.

Select two bolt, nut, and washer assemblies from each R-C lot as shown on shipping containers. Washers must be used on all R-C tests. The coating on washers must be same as on bolt and nut.



6 - 11

For bolts long enough to fit the bolt tension indicator, install bolt, nut, and washer with additional face plates and shims to position three to five threads in the steel plates. Install finger tight.

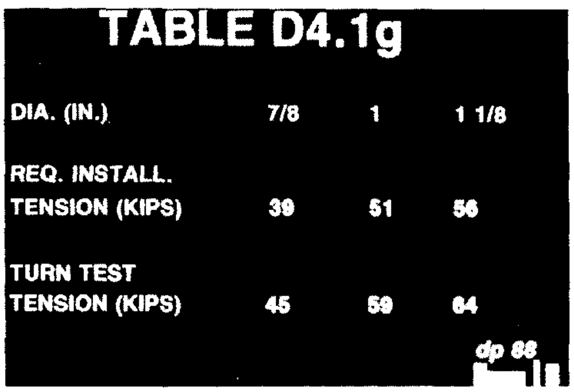


TABLE D4.1g

DIA. (IN.)	7/8	1	1 1/8
REQ. INSTALL. TENSION (KIPS)	39	51	56
TURN TEST TENSION (KIPS)	45	59	64

dp 88

6 - 12

Tighten nut to 10% of specified minimum installation tension. This is a portion of Table D4.1g from the FHWA specification. Explain information. Required installation tension is equal to the proof load tension test requirement of AASHTO M164 (ASTM A325) and is 70% of the minimum specified tensile strength of the bolt.

TABLE D4.1f

ROTATION	BOLT LENGTH
240° (2/3 TURN)	≤ 4 DIA.
360° (1 TURN)	> 4 & ≤ 8 DIA.
480° (1 1/3 TURN)	> 8 DIA.

dp 88

6 - 13

Mark the socket on the nut to reference the point on Skidmore-Wilhelm or shim plates, and rotate the nut as per this chart. Explain chart. Tighten the nut with an air wrench or torque wrench. These rotations are two times required AASHTO Bridge Code rotation for turn-of-nut installation and are not the same rotational requirements as shown in AASHTO M164.

TABLE D4.1g

DIA. (IN.)	7/8	1	1 1/8
REQ. INSTALL. TENSION (KIPS)	39	51	56
TURN TEST TENSION (KIPS)	45	59	64

dp 88

6 - 14

The minimum tension induced into the bolt at the specified rotation shall be equal to or greater than 1.15 times the minimum required installation tension. Table D4.1g has minimum values required and is called Turn Test Tension. Explain numbers.

$$T \leq 0.25\,PD$$

WHERE:
T = MAX. ALLOWABLE TORQUE
P = "TURN TEST TENSION" FROM TABLE D4.1g
D = BOLT DIAMETER (FT.)

dp 88

6 - 15

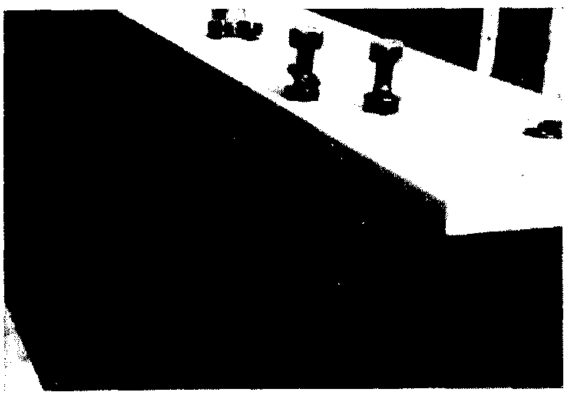
At any point after the required minimum installation tension has been exceeded, one reading of tension and torque shall be taken and recorded. The torque value shall not exceed value calculated from this formula. The readings should be taken as close as possible to the minimum installation tension.

6 - 16

Upon completion of required rotation, the assembly must show no signs of failure. Failure is defined as follows:

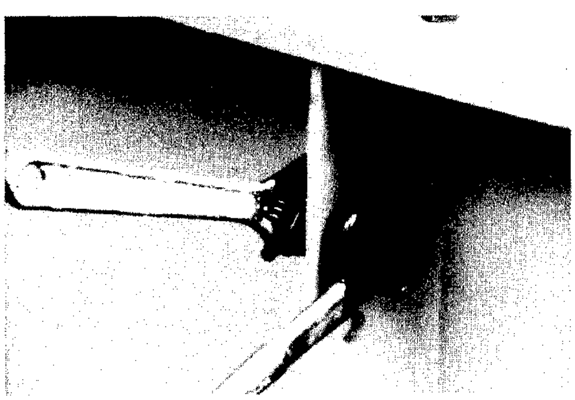
- Inability to assemble to the nut rotation specified in Table D4.1f or by an inability to remove the nut following the test,
- Shear failure of threads as determined by visual examination of bolt and nut threads following removal, and
- Torsional failure of the bolt.

Elongation of bolt, in the threads between the nut and bolt head, is to be expected at the required rotation and is not to be classified as a failure.



6 - 17

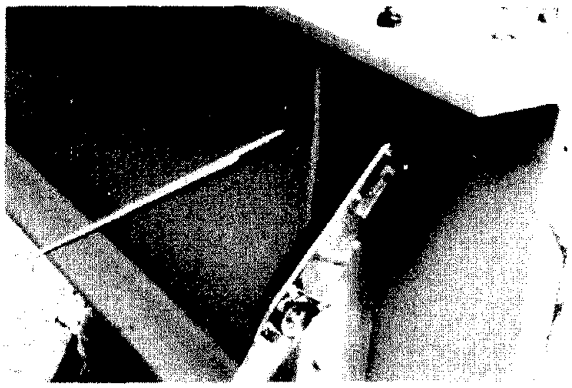
Bolts that are too short to be assembled in a Skidmore-Wilhelm may be tested in a steel joint. Plate thickness is adjusted by steel shims with proper hole size. Minimum turn test tension does not apply as we have no way to measure tension. The maximum torque requirement, using torque formula, is computed using value for P equal to the Turn Test Tension from Table D4.1g.



6 - 18

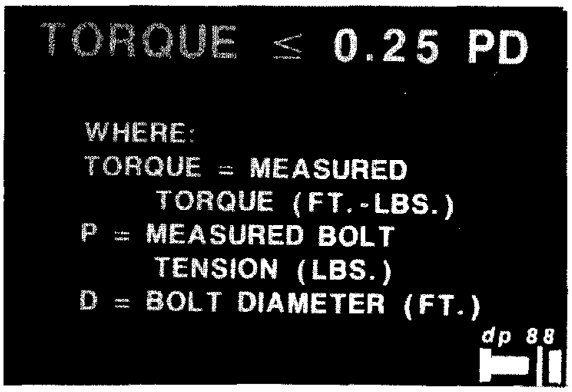
The test procedure essentially same as with the Bolt Tension Calibrator.

- 1 - Install bolt with appropriate shims to place three to five threads in steel plate.
- 2 - Install nut and washer. Prevent bolt head from turning at all times.
- 3 - Tighten nut snug tight using same effort (torque) required to reach 10% on R-C tests done in Skidmore.



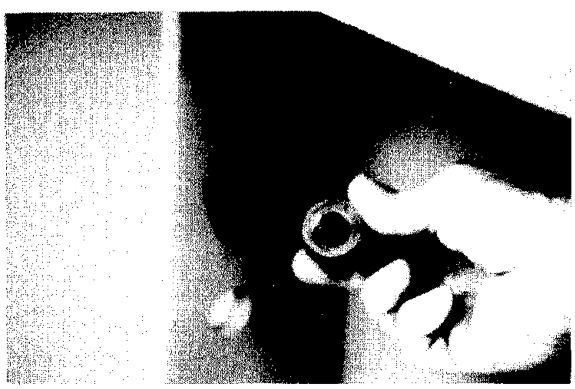
6 - 19

- 4 - Mark socket to reference point on steel plate and turn nut to the minimum rotation required for turn-of-nut installation.
- 5 - Using a calibrated torque wrench, re-start the nut in tightening direction and record torque.



6 - 20

- 6 - Torque cannot exceed value calculated from this formula. P value used in this calculation is the "turn test tension" from table D4.1g of FHWA memo.



6 - 21

- 7 - Nut and bolt must be free from damage as described previously.
- 8 - Test both sets of samples, both must pass test.

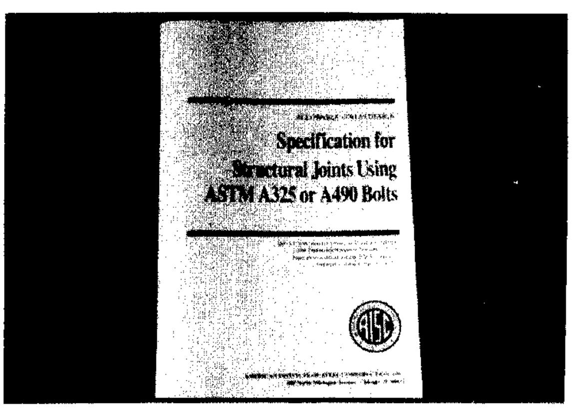
Session 7
Installation—General

7 - 1

Specifications and procedures which cover high strength bolt installation are contained in the latest AASHTO Standard Specification for Highway Bridges.

7 - 2

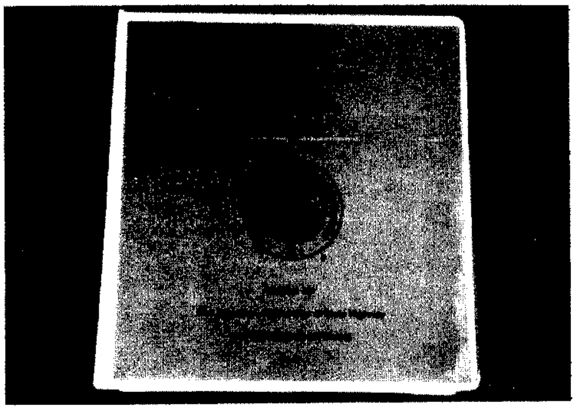
Current edition is the 14th Edition dated 1989 with Interim Specifications - Bridges - 1990. All State DOTs should follow provisions of this specification for all work.



7 - 3

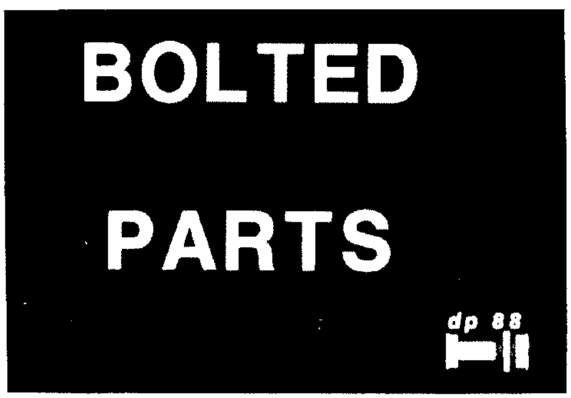
Current AASHTO specifications are very similar to the Research Council on Structural Connections (RCSC) Specification which is titled, "Specification for Structural Joints Using ASTM A325 or A490 Bolts" - 1985 edition.

AASHTO normally adopts RCSC specification requirements usually 2 to 3 years after RCSC publication.



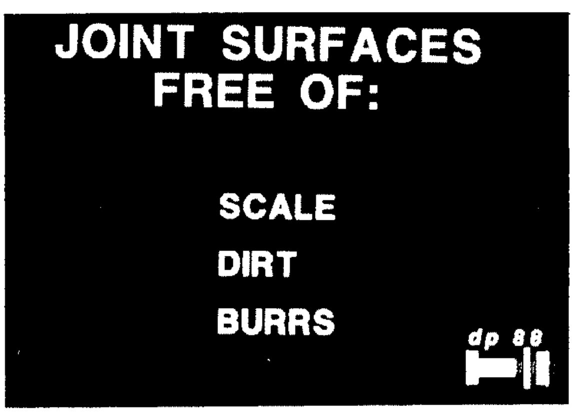
7 - 4

A recent FHWA memorandum will no doubt bring about several changes in AASHTO and ASTM material specifications, as well as RCSC and AASHTO installation specifications. The remainder of course material is based on AASHTO Bridge Code, 14th Edition, 1989, with Interim Specification 1990 as modified where appropriate by FHWA requirements.



7 - 5

All material within the grip of the bolt shall be steel. There shall be no compressible material such as gaskets or insulation within the grip. Bolted steel parts shall fit solidly together after the bolts are tightened, and may be coated or noncoated. The slope of the surfaces of parts in contact with the bolt head or nut shall not exceed 1:20 with respect to a plane normal to the bolt axis.



7 - 6

When assembled, all joint surfaces, including surfaces adjacent to the bolt head and nut, shall be free of scale, except tight mill scale, and shall be free of dirt or other foreign material. Burrs that would prevent solid seating of the connected parts in the snug tight condition shall be removed.

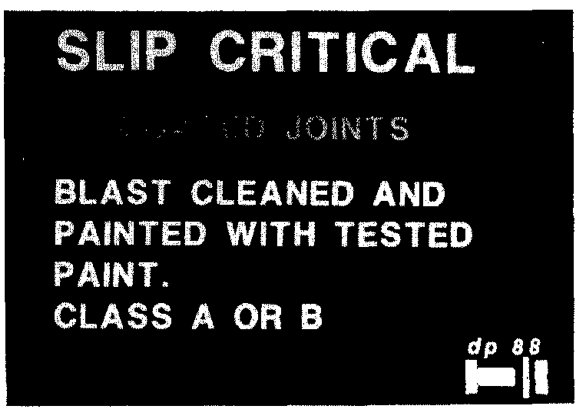
7-7

Paint is permitted on the faying surfaces unconditionally in connections except in slip-critical connections.

Slip-critical joints are defined as joints subject to stress reversal, heavy impact loads, and severe vibration where stress and strain due to joint slippage would be detrimental to the serviceability of the structure.

7-8

The faying surfaces of slip-critical connections shall meet the requirements of the following: In noncoated joints, paint, including any inadvertent overspray, shall be excluded from areas closer than one bolt diameter but not less than one inch from the edge of any hole and all areas within bolt pattern.



7-9

Joints specified to have painted faying surfaces shall be blast cleaned and coated with a paint which has been qualified as class A or B in accordance with the RCSC Specification for Structural Joints using ASTM A325 or A490 bolts. A lesser coefficient of friction may be approved by the Engineer. Coated joints shall not be assembled before the coating has cured for the minimum time used in qualification testing.

7 - 10

Faying surfaces specified to be galvanized shall be hot dip galvanized in accordance with ASTM Specification A123, and shall subsequently be roughened by means of hand wire brushing. Power wire brushing is not permitted.

7 - 11

The following requirements are general and are applicable to all high strength bolt installation methods.

7 - 12

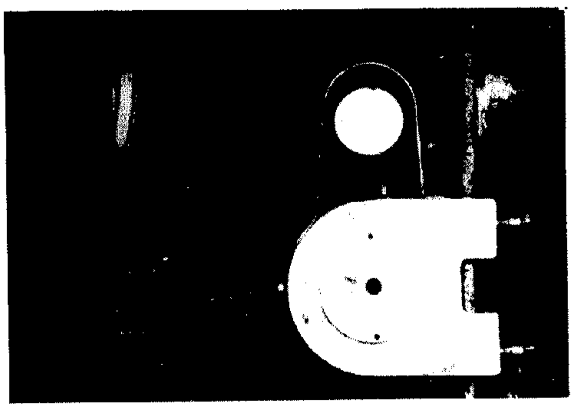
Fasteners shall be protected from dirt and moisture at the job site. Only as many fasteners as are anticipated to be installed and tightened during a work shift shall be taken from protected storage. Fasteners not used shall be returned to protected storage at the end of the shift.

PROTECT LUBRICATION

IF CLEANED AND RE-LUBED ON JOB ROTATIONAL-CAPACITY TESTING IS REQUIRED

7 - 13

Fasteners shall not be cleaned of lubricant that is present in as-delivered condition. Fasteners for slip critical connections which accumulate rust or dirt resulting from job site conditions shall be cleaned and relubricated prior to installation. Rotational capacity testing will be required after cleaning and lubrication.



7 - 14

A tension measuring device shall be at all job sites where high strength bolts are being installed and tightened. The tension measuring device shall be used to confirm:

- The suitability to satisfy the requirements of Table 10.17A of the complete fastener assembly, including lubrication if required, to be used in the work,
- Calibration of the wrenches, if applicable, and
- The understanding and proper use by the bolting crew of the method to be used.

The accuracy of the tension measuring device shall be confirmed through calibration by an approved testing agency at least annually.

TABLE 10.17A - REQUIRED FASTENER TENSION (KIPS)*

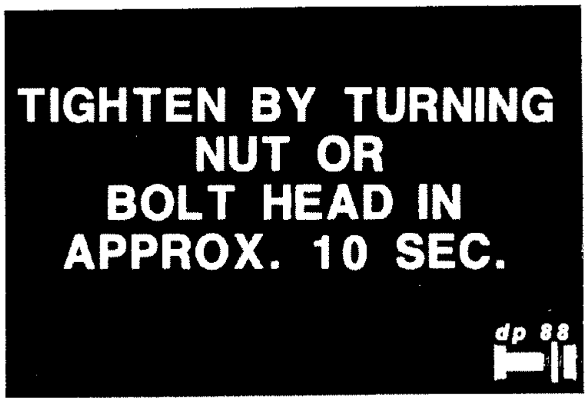
SIZE	A325	A490
3/4	28	35
7/8	39	49
1	51	64

*APPROX. 70% OF MIN. BOLT TENSILE STRENGTH

7 - 15

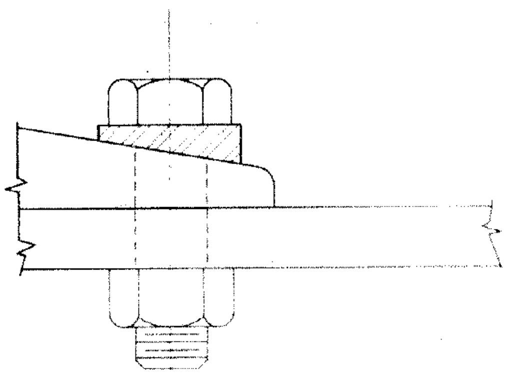
Fasteners, including washers, when required, shall be tightened to at least the minimum tension specified by Table 10.17A by Turn-of-Nut, Calibrated Wrench, Alternate Design Bolt or Direct Tension Indicators.

Complete table is contained in Appendix.



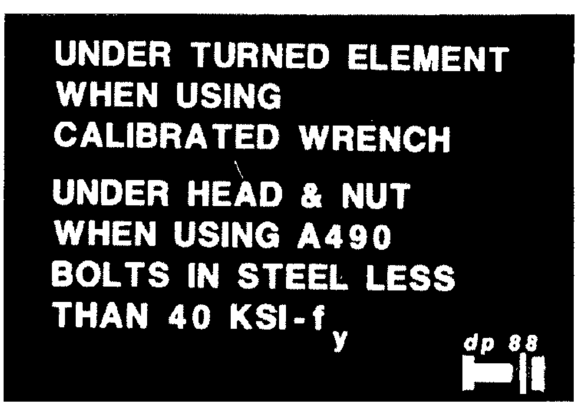
7 - 16

Tightening may be done by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. Impact wrenches, if used, shall be of adequate capacity and sufficiently supplied with air to perform the required tightening of each bolt in approximately 10 seconds.



7 - 17

Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, a hardened beveled washer shall be used to compensate for the lack of parallelism.

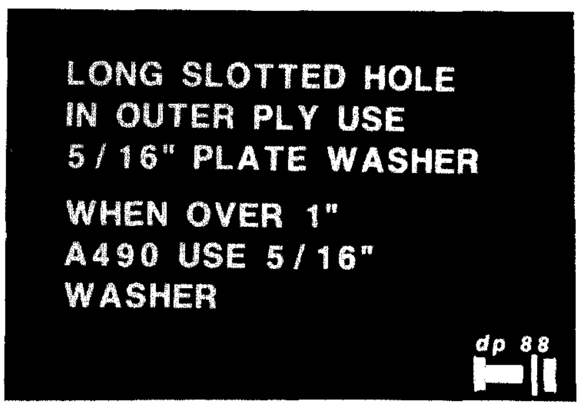


7 - 18

Hardened washers are not required for connections using AASHTO M164 (ASTM A325) and AASHTO M253 (ASTM A490) bolts except as follows: Hardened washers shall be used under the element turned in tightening when the tightening is to be performed by calibrated wrench method. Regardless of the tightening method, hardened washers shall be used under both the head and the nut when AASHTO M253 (ASTM A490) bolts are to be installed in material having a specified yield point less than 40 ksi.

7 - 19

Where AASHTO M164 (ASTM A325) bolts of any diameter or AASHTO M253 (ASTM A490) bolts equal to or less than 1 inch in diameter are to be installed in an oversize or short slotted hole in an outer ply, a hardened washer conforming to ASTM F436 shall be used. When AASHTO M253 (ASTM A490) bolts over 1 inch in diameter are to be installed in an oversize or short slotted hole in an outer ply, hardened washers conforming to ASTM F436 except with 5/16 inch minimum thickness shall be used under both the head and the nut in lieu of standard thickness hardened washers. Multiple hardened washers with combined thickness equal to or greater than 5/16 inch do not satisfy this requirement.



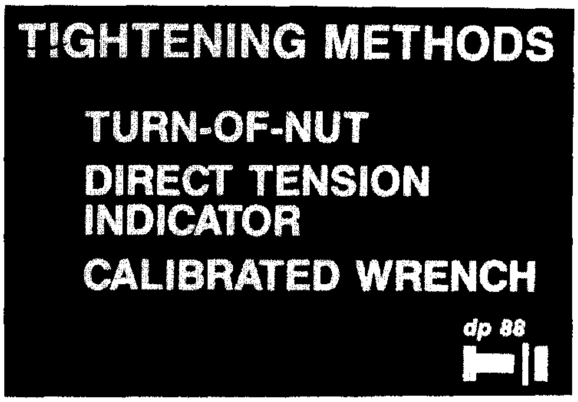
7 - 20

Where AASHTO M164 (ASTM A325) bolts of any diameter or AASHTO M253 (ASTM A490) bolts equal to or less than 1 inch in diameter are to be installed in a long slotted hole in an outer ply, a plate washer or continuous bar of at least 5/16 inch thickness with standard holes shall be provided. The washers or bars shall have a sufficient size to cover completely the slot after installation and shall be of structural grade material, but need not be hardened except as follows. When AASHTO M253 (ASTM A490) bolts over 1 inch in diameter are to be used in long slotted holes in external plies, a single hardened washer conforming to ASTM F436 but with 5/16 inch minimum thickness shall be used in lieu of washers or bars of structural grade material. Multiple hardened washers with combined thickness equal to or greater than 5/16 inch do not satisfy this requirement.

7 - 21

Alternate design fasteners with a geometry which provides a bearing circle on the head or nut with a diameter equal to or greater than the diameter of hardened washers meeting the requirements ASTM F436 satisfy the requirements for washers.

Session 8
Turn-of-Nut Tightening



8 - 1

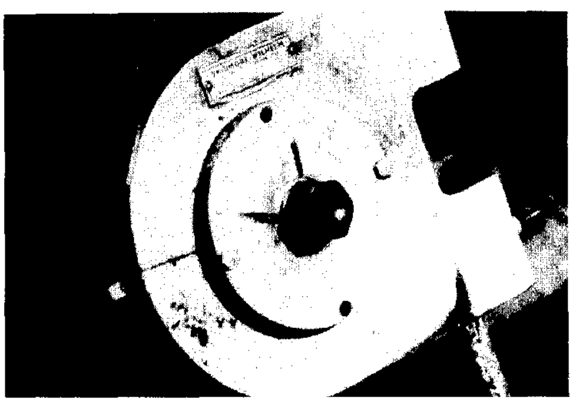
Three tightening methods for conventional bolts, nuts, and washers are included in the AASHTO Bridge Code.

- Turn-of-Nut
- Direct Tension Indicator
- Calibrated Wrench

Detailed discussions of each follows.

8 - 2

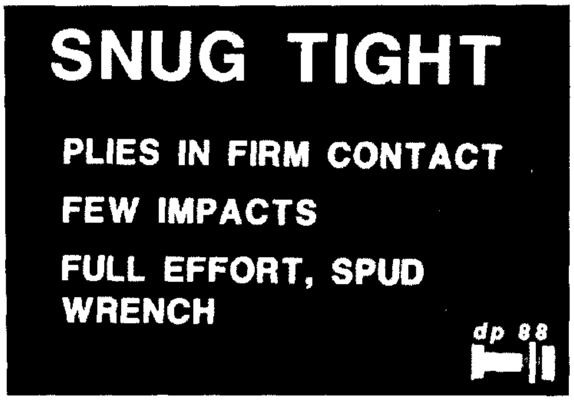
Turn-of-nut tightening makes use of the relationship between thread lead and induced tension in the bolt to provide the necessary clamping force. The procedure was developed in the late 1950s by Bethlehem Steel Corporation as an alternate procedure to the calibrated wrench method . When turn-of-nut tightening is used, hardened washers are not required except as was discussed earlier.



8 - 3

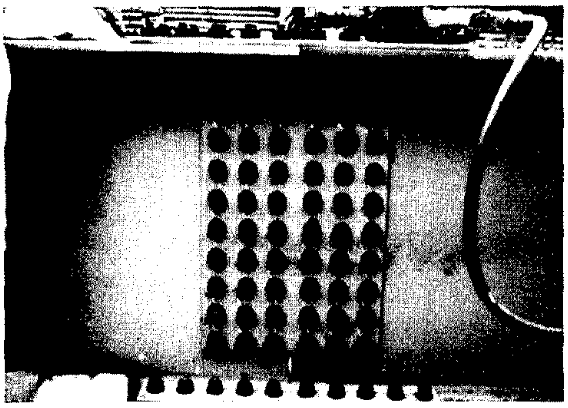
Prior to the start of fastener installation a representative sample of not less than three bolt and nut assemblies of each diameter, length and grade to be used in the work shall be checked in a device capable of indicating bolt tension.

The test shall demonstrate that the method for estimating the snug tight condition and controlling the turns from snug tight to be used by the bolting crew develops a tension not less than 5% greater than the tension required by Table 10.17A. Test is called "Turn-of-nut Verification".



8 - 4

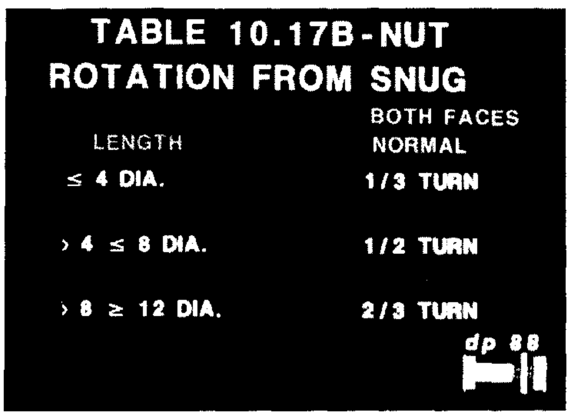
Bolts shall be installed in all holes of the connection and brought to a "snug tight" condition. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench.



8 - 5

Snug tightening shall progress systematically from the most rigid part of the connection to the free edges, and then the bolts of the connection shall be retightened in a similar systematic manner as necessary until all bolts are simultaneously snug tight and the connection is fully compacted.

Explain proper tightening sequence from slide.



8 - 6

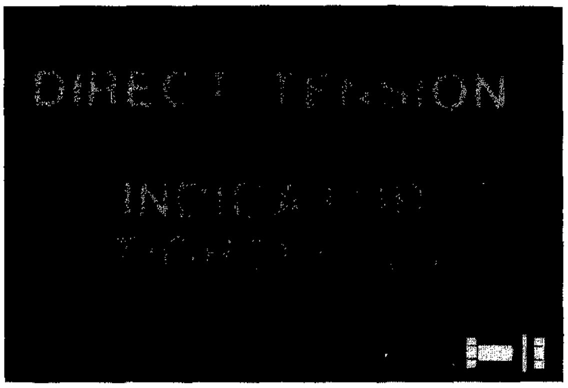
Following this initial operation, all bolts in the connection shall be tightened further by the applicable amount of rotation specified in Table 10.17B. During the tightening operation there shall be no rotation of the part not turned by the wrench. Tightening shall progress systematically from the most rigid part of the joint to its free edges.

Explain table.

See Appendix for complete table.

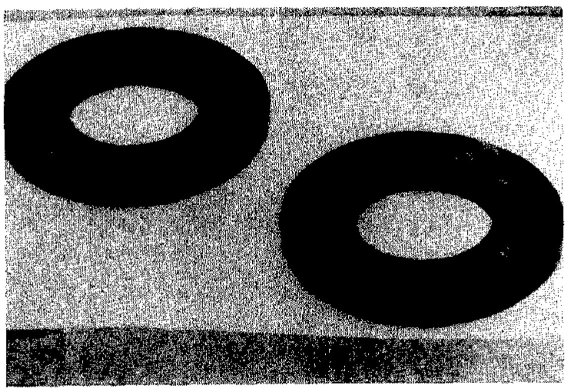
Session 9

Direct Tension Indicators



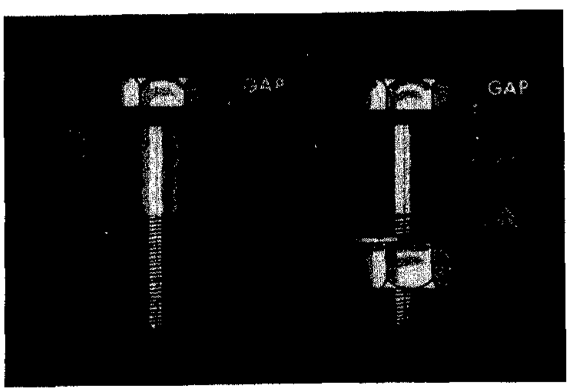
9 - 1

A direct tension indicator (DTI) is a device which indicates the bolt tension without relying on a torque-tension relationship. The most common type of DTI is a crushable washer. The behavior and use of washer-type DTI's will be discussed in this section.



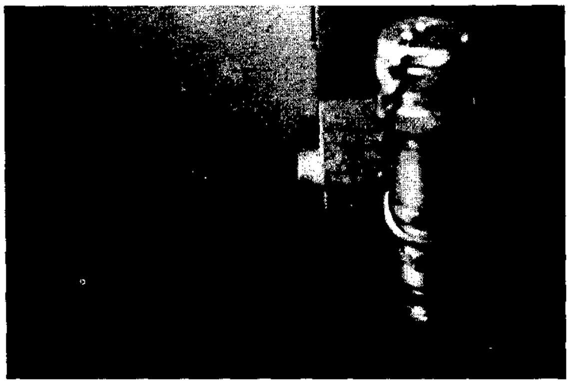
9 - 2

A typical DTI is shown in Figure 9-2. The washers are covered by ASTM Specification F959. They are to have the manufacturer's marking on them and the grade of bolt they are to be used with.



9 - 3

Figure 9-3 shows a typical installation of a DTI. As the nut is tightened, the protrusions on the washers are plastically deformed. The gap between the washer and bolt head is measured in the spaces between the protrusions. The gap is used to indicate the tension in the bolt.

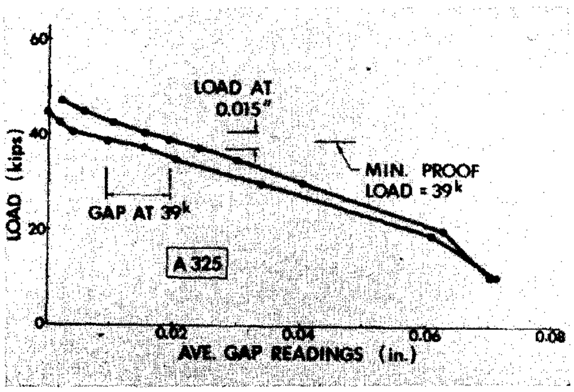


9 - 4

The performance of the DTIs should be checked in the field before the start of bolting. A tension measuring device is used along with a special adaptor at the bolt head. This adaptor replaces the normal piece used to prevent bolt head rotation.

9 - 5

The bolt is tightened to 1.05 times the required installation tension and the gap is measured using tapered leaf thickness (feeler) gages. The average gap must equal or exceed 0.015 inches for plain DTIs and 0.005 inches for coated DTIs. Note the value of 1.05 times the required tension is higher than the minimum value in ASTM F959. The requirement of 1.05 times the required tension is required in the AASHTO and the Research Council Specifications.



9 - 6

The graph in Figure 9-6 shows the typical performance of a DTI. As the bolt tension is increased, the gap decreases. Some variability exists in the gap-tension relationship. Three DTIs of each diameter must be tested and meet the requirements to account for this variability. In addition, the bolt tension is set at 1.05 times the required installation tension to further account for the variability of the measurement. Tightening beyond crushing of the protrusion should not be allowed. The bolt tension is unknown when crushing occurs. Failure of the bolt may occur.

9-7

Care should be exercised during testing and installation of DTIs to prevent turning of the bolt head against the DTI. The turning will gall the protrusion and reduce the gap. The result will be a small gap which gives a false indication of bolt tension. A two-person bolting crew is required with DTIs to insure that the head of the bolt does not turn and to monitor the gap during tightening.

Use of a DTI under the turned element requires the use of a hardened washer between the DTI and the element. The washer should not turn against the DTI. It is very difficult to insure that the washer does not rotate during installation. Consequently, use of DTIs under the turned element should be discouraged. If the DTI is to be used under the turned element in the work, the field check should be performed using this arrangement.

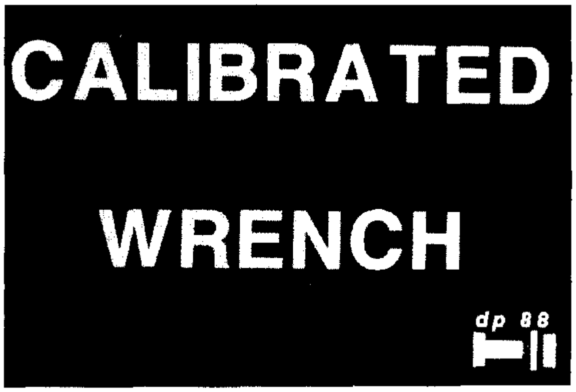
9-8

The deformation which occurs in the protrusions is plastic. Removal of the bolt tension does not cause the gap to increase. The DTI should not be crushed to the specified gap during snugging since snugging of adjacent bolts will reduce bolt tension but the DTI gap will not change. This will cause the DTI to give a false indication of bolt tension.

Turning of the nut during final tightening beyond crushing of the DTI can cause bolt failure. The tension required to crush the washer can exceed the bolt strength. Tightening beyond crushing should not be allowed.

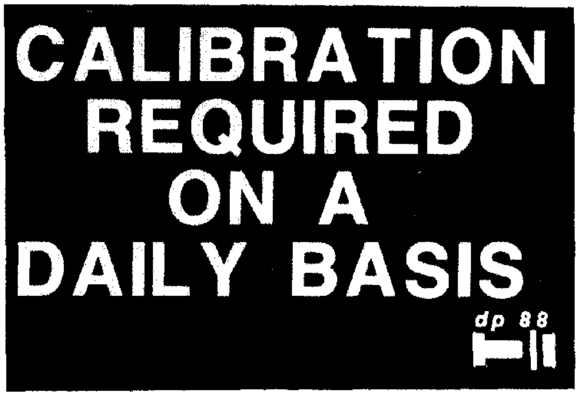
Session 10

Calibrated Wrench Tightening



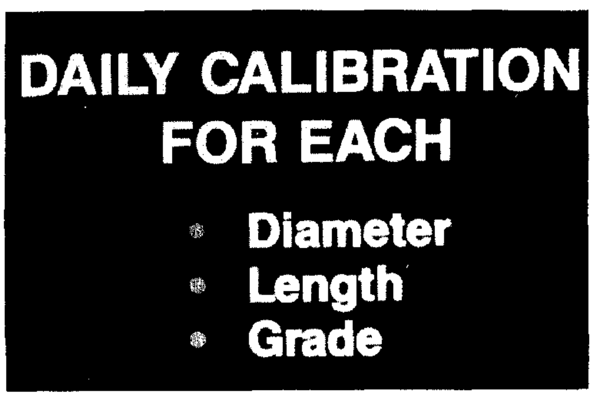
10 - 1

Calibrated wrench tightening relies on a certain torque load to induce proper tension in the bolt. The method was previously deleted from AASHTO Bridge Code and was only re-inserted in 1988 with strict controls on jobsite procedures. Numerous variables which are not related to tension affect torque. Specified installation procedures must be followed to assure proper fastener tension.



10 - 2

Calibrated wrench tightening may be used only when installation procedures are calibrated on a daily basis and when a hardened washer is used under the element turned in tightening. The AASHTO specification does not recognize standard torques determined from tables or from formulas which are assumed to relate torque to tension. When calibrated wrenches are used for installation, they shall be set to provide a tension not less than 5 percent in excess of the minimum tension specified in Table 10.17A.

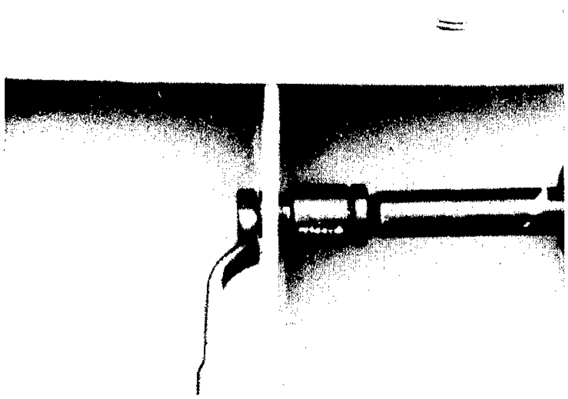


10 - 3

The installation procedures shall be calibrated at least once each working day for each bolt diameter, length and grade using fastener assemblies that are being installed in the work.

10 - 4

Calibration shall be accomplished in a device capable of indicating actual bolt tension by tightening three typical bolts of each diameter, length and grade from the bolts being installed and with a hardened washer from the washers being used in the work under the element turned in tightening.

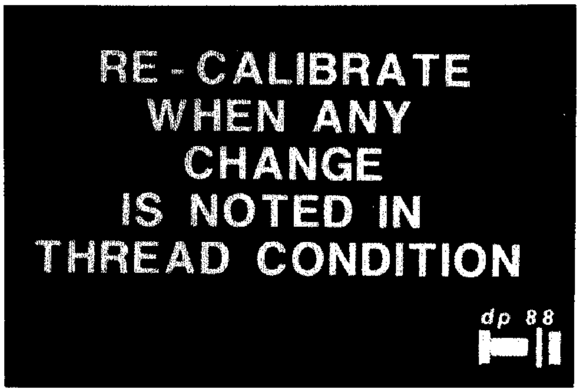


10 - 5

Bolts that are too short for the tension indicating device may be tested using direct tension indicators (DTIs). The DTI will give an indication of the tension load in short bolts and allow the establishment of the torque to tension ratio.

10 - 6

The DTIs must be "calibrated" in a tension indicating device to determine the applicable DTI clearance at a load 5% over the specified minimum bolt tension. For accurate calibration DTI must go under bolt head. When using Skidmore-Wilhelm equipment, the inserts must be modified to place the nut on the back side and allow tightening from the nut side. Once the DTIs are calibrated, they are used on the short bolts to set the installation wrenches at the required bolt tension. DTIs must be placed under bolt head.

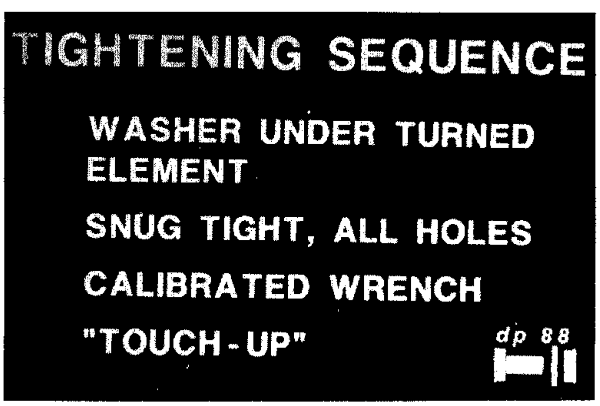


10 - 7

Wrenches shall be recalibrated when significant difference is noted in the surface condition of the bolt threads, nuts or washers. Recalibration is also required when fasteners are installed which may have been cleaned and/or relubricated.

10 - 8

It shall be verified during actual installation in the assembled steelwork that the wrench adjustment selected by the calibration does not produce a nut or bolt head rotation from snug tight greater than that permitted in Table 10.17B. If manual torque wrenches are used, nuts shall be turned in the tightening direction when torque is measured.



10 - 9

When calibrated wrenches are used to install and tension bolts in a connection, bolts shall be installed with hardened washers under the element turned in tightening bolts in all holes of the connection and brought to a snug tight condition. Following this initial tightening operation, the connection shall be tightened using the calibrated wrench. Tightening shall progress systematically from the most rigid part of the joint to its free edges. The wrench shall be returned to "touch up" previously tightened bolts which may have been relaxed as a result of the subsequent tightening of adjacent bolts until all bolts are tightened to the prescribed amount.

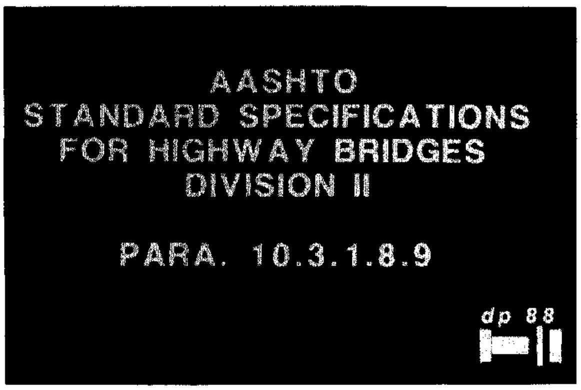
Session 11

Alternate Design and Lock Pin and Collar Fasteners

11 - 1

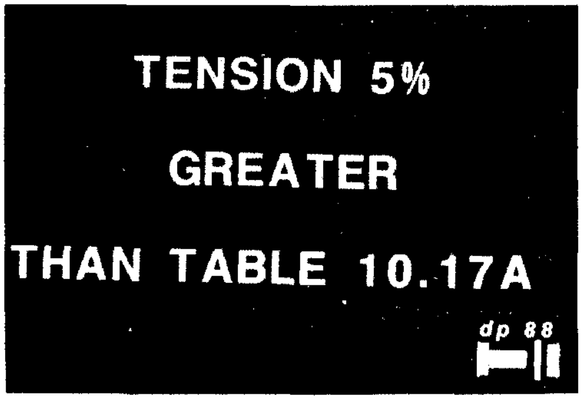
ALTERNATE DESIGN FASTENERS

When fasteners which incorporate a design feature intended to indirectly indicate the bolt tension or to automatically provide the tension required by Table 10.17A and which have been qualified under Article 10.3.1.8.9 are to be installed, a representative sample of not less than three bolts of each diameter, length and grade shall be checked at the job site in a device capable of indicating bolt tension.



11 - 2

10.3.1.8.9 - Other fasteners or fastener assemblies which meet the materials, manufacturing, and chemical composition requirements of AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490), and which meet the mechanical property requirements of the same specification in full-size tests, and which have body diameter and bearing areas under the head and nut, or their equivalent, not less than those provided by a bolt and nut of the same nominal dimensions prescribed in the previous paragraph, may be used subject to the approval of the Engineer. Such alternate fasteners may differ in other dimensions from those of the specified bolts and nuts. Their installation procedure may differ from those specified and their inspection may differ from that to be discussed later. When a different installation procedure or inspection is used, it shall be detailed in a supplemental specification applying to the alternate fastener and that specification must be approved by the Engineer.



11 - 3

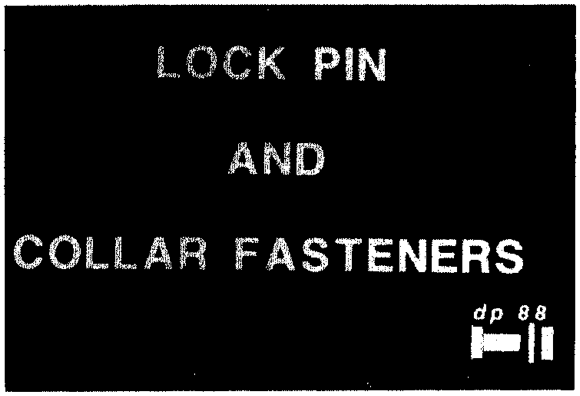
The test assembly shall include flat hardened washers, if required in the actual connection, arranged as in the actual connections to be tensioned. The calibration test shall demonstrate that each bolt develops a tension not less than 5 percent greater than the tension required by Table 10.17A. Manufacturer's installation procedure as required by Article 10.3.1.8.9 shall be followed for installation of bolts in the calibration device and in all connections.

11 - 4

When alternate design fasteners which are intended to control or indicate bolt tension of the fasteners are used, bolts shall be installed in all holes of the connection and initially tightened sufficiently to bring all plies of the joint into firm contact but without yielding or fracturing the control or indicator element of the fasteners.

11 - 5

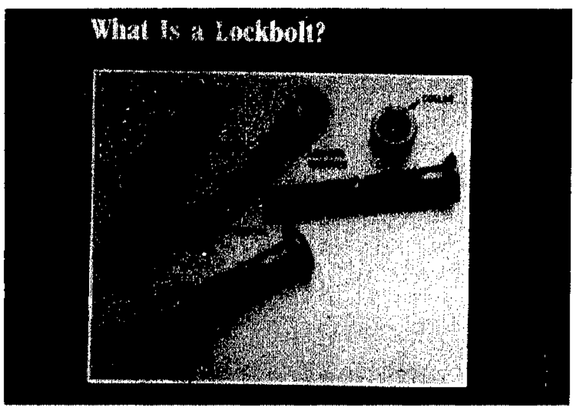
All fasteners shall then be further tightened, progressing systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final twistoff of the control or indicator element of individual fasteners.



11 - 6

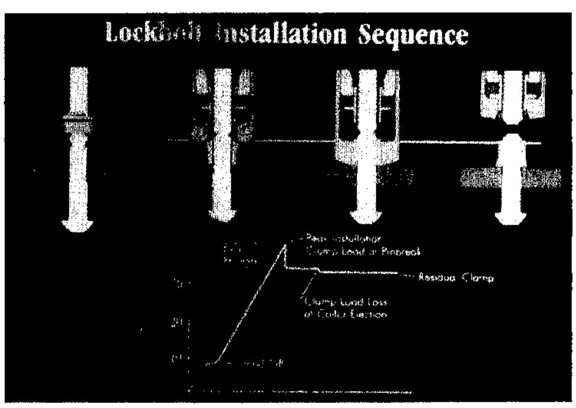
LOCK PIN AND COLLAR FASTENERS

The installation of lock-pin and collar fasteners shall be by methods and procedures approved by the Engineer.



11 - 7

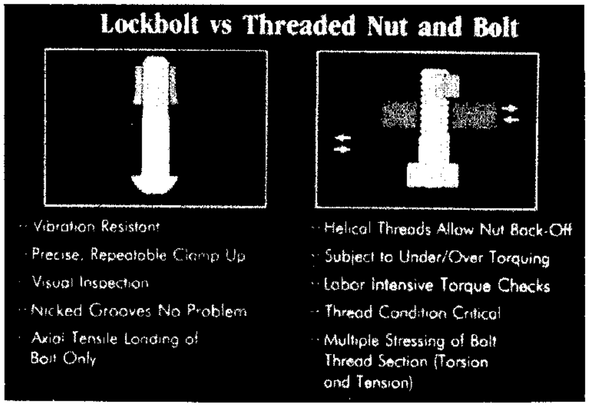
The lock pin and collar provides carbon steel strength grade A325 in nominal diameters from 1/2" to 11/8". Lockbolts have been used for 50 years in construction and transportation applications. These fasteners meet the ASTM specification for A325 bolts.



11 - 8

The locking collar is swaged into the locking grooves on the pin by the application of direct tension.

- The installation tool "holds" onto the pintail and applies a "push-pull" action on the collar and pin.
- When the tensile force applied exceeds the plastic limit of the collar, it begins to swage and progressively engages in the locking grooves on the pin.
- The swage action continues until the swaging anvil of the nose assembly contacts the work or collar flange.
- As the tool continues to apply direct tension force to the pin, it will fail in tension at the completion of the installation cycle in the breakneck groove.



11 - 9

Many comparisons have been made between swage lock fasteners and threaded bolt/nut systems. There are significant differences in the forces applied and the action of their application to fastener components.

Clamp force is created by the application of direct tension to the pin and collar. The force needed for installation is controlled by the interaction of the tool and fastener.

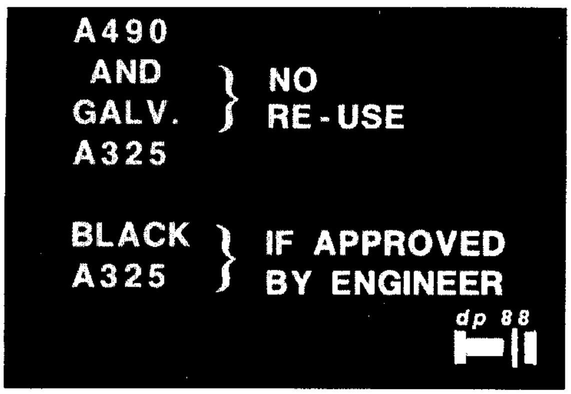
Session 12

Re-Use and Inspection

12 - 1

RE-USE OF FASTENERS

In some cases it may become necessary to remove previously tightened fasteners from the structure. The Engineer or inspector is usually requested to allow the re-use of the fasteners. The AASHTO Bridge Code states as follows:



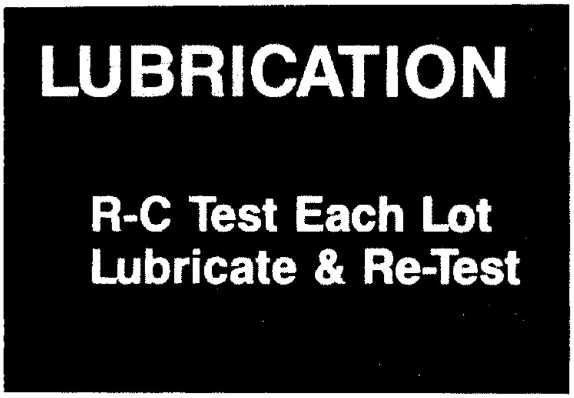
12 - 2

AASHTO M253 (ASTM A490) bolts and galvanized AASHTO M164 (ASTM A325) bolts shall not be reused. Only black AASHTO M164 (ASTM A325) bolts may be reused if approved by the Engineer responsible. Touching up or retightening previously tightened bolts which may have been loosened by the tightening of adjacent bolts shall not be considered as reuse provided the snugging up continues from the initial position and does not require greater rotation, including the tolerance, than that required by Table 10.17B.

12 - 3

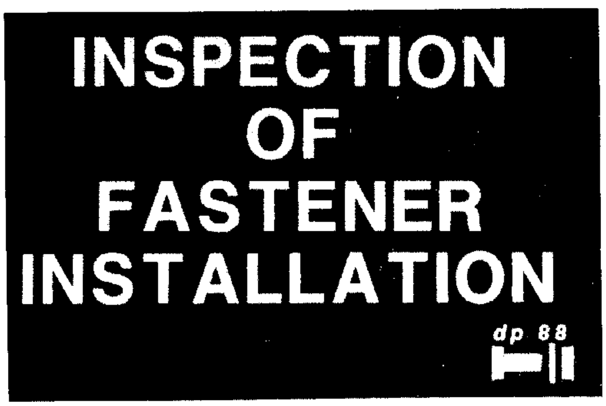
The following criteria should be used by the Engineer to evaluate whether or not AASHTO M164 (ASTM A325) fasteners can be reused:

1) There should be no excessive elongation of the bolt in the threaded area which would be present if the bolt had been overtightened. If the nut can be installed by hand for the full thread length, no overtightening is evident. Check every bolt with nut which was used during initial installation.



12 - 4

2) Adequate lubrication must be present. All fasteners to be reused must be completely removed from the structure and grouped together to form lots according to the length of time they have been installed. R-C test each lot. Fasteners which fail test can be lubricated and re-tested. Re-use should be limited to one (1) time.



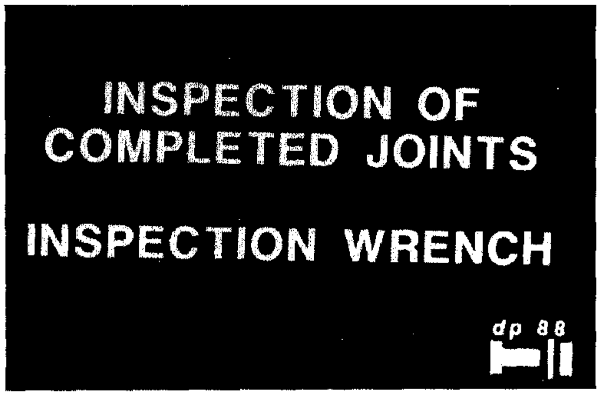
12 - 5

INSPECTION OF FASTENER INSTALLATION

The Engineer shall determine that the requirements of the following are met in the work. These requirements apply equally to fasteners which may be installed and tightened in the fabrication shop.

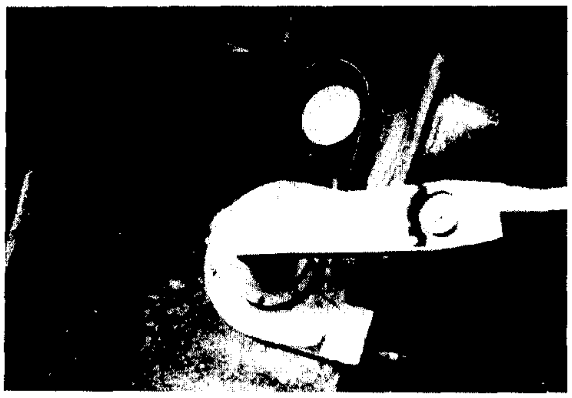
12 - 6

Before the installation of fasteners in the work, the Engineer shall check the marking, surface condition and storage of bolts, nuts and washers and the faying surfaces of joints for compliance with the requirements as previously discussed. He shall observe calibration and/or testing procedures required to confirm that the selected procedure is properly used and that, when so used with the fastener assemblies supplied, the tensions specified in Table 10.17A are provided. He shall monitor the installation of fasteners in the work to assure that the selected procedure, as demonstrated in the initial testing to provide the specified tension, is routinely properly applied.



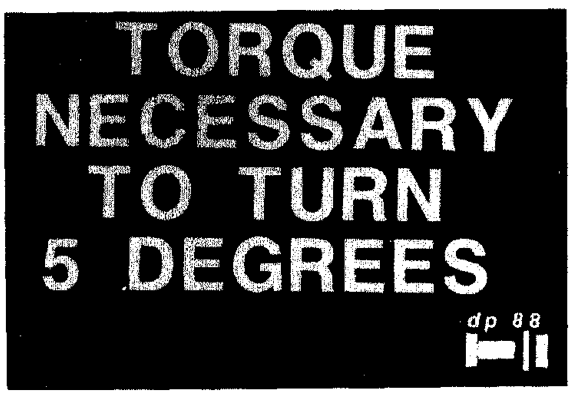
12 - 7

In addition to the above, inspection of completed joints is required. The following inspection procedure shall be used unless a different procedure is specified in the contract documents. Either the Engineer or the Contractor in the presence of the Engineer, at the Engineer's option, shall use an inspection wrench which may be a torque wrench.



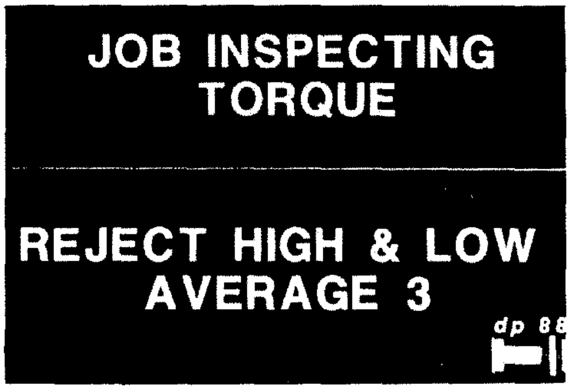
12 - 8

At least once each day, a representative sample of five bolts from the diameter, length and grade of the bolts used in the work shall be tightened in the tension measuring device by any convenient means to an initial condition equal to approximately 15 percent of the required fastener tension and then to the minimum tension specified in Table 10.17A. There shall be a washer under the part turned in tightening each bolt if washers are so used on the structure. Tightening beyond the initial condition must not produce greater nut rotation than 1½ times that permitted in Table 10.17B.



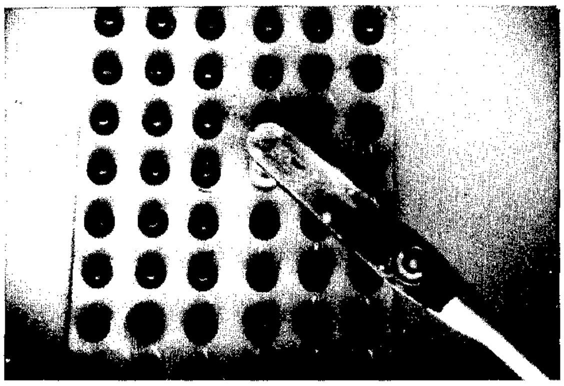
12 - 9

The inspecting wrench shall then be applied to the tightened bolts and the torque necessary to turn the nut or head 5 degrees (approximately 1" at 12" radius) in the tightening direction shall be determined. From a practical standpoint this is the torque necessary to just start rotation of the nut or bolt head. Turn from same side turned during installation.



12 - 10

The job inspecting torque shall be taken as the average of three values thus determined after rejecting the high and low values.



12 - 11

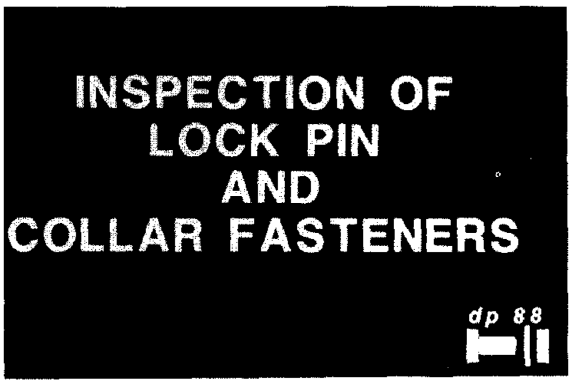
Bolts represented by the sample in the foregoing paragraph which have been tightened in the structure shall be inspected by applying, in the tightening direction, the inspecting wrench and its job torque to 10% of the bolts, but not less than 2 bolts, selected at random in each connection in question. If no nut or bolt head is turned by the application of the job inspecting torque, the connection shall be accepted as properly tightened. If any nut or bolt is turned by the application of the job inspecting torque, all bolts in the connection shall be tested, and all bolts whose nut or head is turned by the job inspecting torque shall be tightened and reinspected. Alternatively, the fabricator or erector, at his option, may retighten all of the bolts in the connection and then resubmit the connection for the specified inspection.

12 - 12

The AASHTO Specification does not recognize standard torques determined from tables or from formulas which are assumed to relate torque to tension. Testing using such standard torques shall not be considered valid. Torque to Tension ratio is governed by many variables and must be determined on each project on a daily basis.

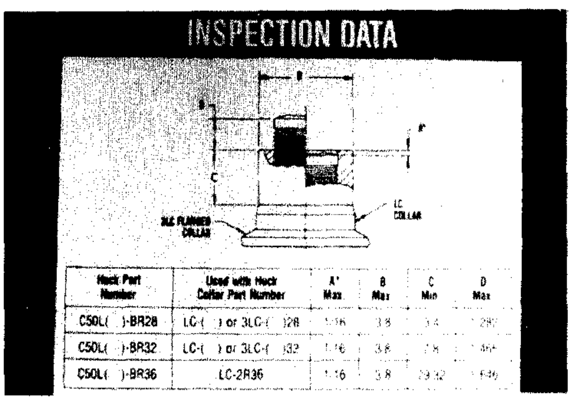
12 - 13

The procedure discussed is intended for inspec- tion of bolted connections and verification of pretension at the time of tensioning the joint. If verification of bolt tension is required after a passage of a period of time and exposure of the completed joints, the procedures discussed will provide an indication of bolt tension which is of questionable accuracy. Procedures appropriate to the specific situation should be used for verification of bolt tension. This might involve use of the inspection procedure discussed or might require the development and use of alternate procedures.



12 - 14

The procedures for inspecting and testing lock-pin and collar fasteners and their installation to assure that the required preload tension is provided shall be as approved by the Engineer.



12 - 15

The installed fastener can be visually inspected for pin position, swage diameter, and length. The illustration shows those dimensions which can be visually inspected, checked with simple measuring instruments, or by simple go-no go gauges available.

Installed fastener values become a function of material and dimensional control at the manufacturing source and are independent of operator skill.

APPENDIX A1

PROCEDURE FOR PERFORMING ROTATIONAL CAPACITY TEST LONG BOLTS IN TENSION CALIBRATOR

EQUIPMENT REQUIRED:

1. Calibrated bolt tension measuring device of size required for bolts to be tested. Mark off a vertical line and lines 1/3 of a turn, 120 degrees; and 2/3 of a turn, 240 degrees, from vertical in a clockwise direction on the face plate of the calibrator.

2. Calibrated torque wrench.

3. Spacers and/or washers with hole size no larger than 1/16 in. greater than bolt to be tested.

4. Steel section to mount bolt calibrator. Flange of girder or cross frame accessible from the ground is satisfactory.

PROCEDURE:

1. Install nut on bolt and measure stick out of bolt when 3 to 5 full threads of the bolt are located between the bearing face of the nut and the bolt head. Measure the bolt length, the distance from the end of the threaded shank to the underside of the bolt head.

2. Install the bolt into the tension calibrator and install the required number of shim plates and/or washer (one washer under the nut must always be used) to produce the thread stickout measured in Step 1.

3. Tighten bolt using a hand wrench to the snug tensions listed below -0 kips, +2 kips.

Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
Snug Tension (kips)	1	2	3	4	5	6	7	9	10

4. Match mark the nut to the vertical stripe on the face plate of the bolt calibrator.

5. Using the calibrated manual torque wrench, tighten the bolt to at least the tension listed below and record the torque required to reach the tension and the value of the bolt tension. Torque must be measured with the nut in motion.

Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
Tension (kips)	12	19	28	39	51	56	71	85	103

6. Further tighten the bolt to the rotation listed below. The rotation is measured from the initial marking in Step 4. Record the bolt tension. Assemblies which fail prior to this rotation either by stripping or fracture fail the test.

Bolt Length (measured in Step 1)	4 x bolt dia. or less	Greater than 4 but no more than 8 x bolt dia.	Greater than 8x bolt dia.
Required Rotation	2/3	1	1-1/3

7. The bolt tension measured in Step 6 after the required rotation must equal or exceed the values in the table shown below. Assemblies which do not meet this tension have failed the test.

Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
Tension (kips)	14	22	32	45	59	64	82	98	118

8. Loosen and remove nut, and examine the threads on the nut and bolt. No signs of thread shear failure, stripping, or torsional failure of the bolt should be evident. Assemblies which have evidence of stripping have failed the test.

9. Calculate and record the value of 0.25x the tension (pounds=kips x 1000) measured in Step 5 x the bolt diameter in feet. The torque measured and recorded in Step 5 must be equal to or less than this calculated value. Assemblies with torque values exceeding this calculated value failed the test.

PROCEDURE FOR PERFORMING ROTATIONAL CAPACITY TEST
BOLTS TO SHORT TO FIT TENSION CALIBRATOR

EQUIPMENT REQUIRED:

1. Calibrated torque wrench and an spud wrench or equivalent.

2. Spacers and/or washers with hole size no larger than 1/16 in. greater than bolt to be tested.

3. Steel section with normal size hole to install bolt. Any available splice hole can be used with a plate thickness that will provide the number of threads under the nut required in Step 1 below. Mark off a vertical line and lines 1/3 of a turn, 120 degrees; 1/2 of a turn, 180 degrees; and 2/3 of a turn, 240 degrees, from vertical in a clockwise direction on the plate.

PROCEDURE:

1. Install nut on bolt and measure stick out of bolt when 3 to 5 full threads of the bolt are located between the bearing face of the nut and the bolt head. Measure the bolt length, the distance from the end of the threaded shank to the underside of the bolt head.

2. Install the bolt into the hole and install the required number of shim plates and/or washer (one washer under the nut must always be used) to produce the thread stickout measured in Step 1.

3. Snug the bolt using a hand wrench. The snug condition should be the normal effort applied to a 12 inch long wrench. The applied torque should not exceed 20% of the torque determined in Step 5.

4. Match mark the nut to the vertical stripe on the plate.

5. Tighten the bolt by turning the nut using the torque wrench to the rotation listed below. A second wrench must be used to prevent rotation of the bolt head during tightening. Record the torque required to reach this rotation. Torque must be mesured with the nut in motion.

Bolt Length (measured in Step 1)	4 x bolt dia. or less	Greater than 4 but no more than 8 x bolt dia.	Greater than 8 x bolt dia.
Required Rotation	1/3	1/2	2/3

The measured torque should not exceed the values listed below. Assemblies which exceed the listed torques have failed the test.

Bolt Dia. (in.)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
Torque (ft-lbs)	150	290	500	820	1230	1500	2140	2810	3690

6. Tighten the bolt further to the rotation required below. The rotation is measured from the initial marking in Step 4. Assemblies which fail prior to this rotation either by stripping or fracture fail the test.

Bolt Length (measured in Step 1)	4 x bolt dia. or less	Greater than 4 but no more than 8 x bolt dia.	Greater than 8 x dia.
Required Rotation	2/3	1	1-1/3

7. Loosen and remove nut, and examine thread on the nut and bolt. No signs of thread shear failure, stripping, or torsional failure of the bolt should be evident. Assemblies which have evidence of stripping have failed the test.

Appendix A2
Procedure for Installation and Tightening of High-Strength Fasteners
Turn-of-Nut Method

1.0 <u>BOLTED PARTS AND GENERAL PROVISIONS</u>

1.1 Material within the bolt grip will be steel with no compressible material.

1.2 Slope of surface shall not exceed 1:20. Correct with hardened beveled washers.

1.3 All surfaces free of loose scale, dirt or other foreign material.

1.4 Uncoated joints shall have no paint, including overspray, in the connection area.

1.5 Painted joints shall be blast cleaned and coated with an approved paint. Joints shall not be assembled until paint has cured for the minimum time used in paint qualification testing.

1.6 Galvanized joints shall be roughened by hand wire brushing prior to assembly.

1.7 All fastener components shall be properly lubricated and protected from contamination, dirt and moisture.

1.8 Hardened washers may be required for standard holes or special washers may be required for oversize or slotted holes. See specifications.

1.9 Tightening may be done by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. Impact wrenches, if used, shall be of adequate capacity and sufficiently suppled with air to perform the required tightening of each bolt in approximately 10 seconds.

2.0 <u>TURN-OF-NUT VERIFICATION TESTING</u>

2.1 Equipment required - Calibrated bolt tension measuring device. Spacers and/or washers with proper hole size. Rigid mounting for bolt tension calibrator. Air impact wrenches to install fasteners in the structure.

2.2 Select at least 3 bolt, nut and washer (when required) assemblies of each diameter, length and grade to be used in the work.

2.3 Install and tighten each assembly in the bolt tension measuring device using the snug tightening procedure which will be used to snug tight the fasteners in the work. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. Assure the proposed "snug tightening" procedure does not produce more than 50% of required fastener tension as specified by Table 10.17A below. If so, revise snug tightening procedure.

TABLE 10.17A - REQUIRED FASTENER TENSION (Kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

2.4 Following snug tightening, mark nut or drive socket to a reference point on bolt tension calibrator and further tighten to the rotation shown below.

Bolt Length	4 x bolt dia. or less	Greater Than 4 but no more than 8x bolt dia.	Greater than8 x bolt dia.
Required Rotation	1/3	1/2	2/3

2.5 At this rotation, the minimum bolt tension shall be as follows:

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

3.0 SNUG TIGHTENING PROCEDURE

3.1 Bolts shall be installed in all holes of the connection and brought up to a "snug tight" condition.

3.2 Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. Adequate tightness may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. The snug tightening procedure used in the work shall be the same snug tightening procedure used when conducting the TURN-OF-NUT VERIFICATION TEST in paragraph 2.3.

3.3 Snug tightening shall progress systematically from the most rigid part of the connection to the free edges. Start the pattern near the end of each member being spliced at the center of the pattern and work toward all edges of the splice plate.

3.4 Following this initial snug tightening, all bolts in the joint shall be again systematically tightened as necessary using a similar pattern until all bolts are simultaneously snug tight and the connection is fully compacted.

4.0 FINAL TURN-OF-NUT TIGHTENING

4.1 Following this snug tightening operation, all bolts in the connection shall be tightened by the applicable amount of rotation as specified in Table 10.17 B below.

TABLE 10.17B--NUT ROTATION FROM SNUG TIGHT

Bolt Length	Both Faces Normal	One Face Normal -- One Face Sloped Not More Than 1:20	Both Faces sloped Not More Than 1:20
4 x dia. or less	1/3 turn	1/2 turn	2/3 turn
Greater than 4 but no more than 8 x bolt dia.	1/2 turn	2/3 turn	5/6 turn
Greater than 8 x bolt dia. not exceeding 12x	2/3 turn	5/6 turn	1 turn

4.2 During the tightening operation there shall be no rotation of the part not turned by the wrench.

4.3 Tightening shall progress systematically from the most rigid part of the joint to its free edges. Start the pattern near the end of each member being spliced at the center of the pattern and work toward all edges of the splice plate.

5.0 COMMENTARY

5.1 Tension Calibrating Devices: At the present time, there is no known economical means for determining the tension in a bolt that has previously been installed in a connection. The actual tension in a bolt installed in a tension calibrator (hydraulic tension indicating device) is directly indicated by the dial of the device, provided the device is properly calibrated. Such a device is an economical and valuable tool that should be readily available whenever high-strength bolts are to be tensioned to the specified pretension. Although each element of a fastener assembly may conform to the minimum requirements of their separate material specifications, their compatibility in an assembly or the need for lubrication can only be assured by testing of the assembly. Hence, such devices are important for confirming the complete fastened assembly as it will be used with the method or tightening to assure the suitability of bolts and nuts, including lubrication, and the adequacy of impact wrenches and/or air pressure, to provide the specified bolt tension.

Testing before start of installation of fasteners in the work will identify potential sources of problems including, but not necessarily limited to, the need for lubrication to prevent failure of bolts by combined high torque with tension, under strength assemblies due to improper marking or heat treatment or quality control of fasteners, excessive overtapping of hot-dip galvanized nuts, improper use of selected installation method by the bolting crews and/or improper or unreliable inspection techniques by inspectors. Such devices are essential to the confirmation testing of fasteners different from AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) bolts, when approved by the Engineer of Record, and direct tension indicators.

They are also essential to the specified procedure for the calibrated wrench method of installation, as well as for confirmation demonstration of proper use of any method by the bolting crews. They are essential for the specified procedure for arbitration inspection. They are the only known economically available tool for field use for determining realistic torque to tension relationships for given fastener assemblies.

Hydraulic tension calibrating devices capable of indicating bolt tension undergo a slight deformation under load. Hence the nut rotation corresponding to a given tension reading may be somewhat larger than it would be if the same bolt were tightened against a solid steel abutment.

Stated differently, the reading of the calibrating device tends to under estimate the tension which a given rotation of the turned element would induce in a bolt in an actual joint. This should be borne in mind when using such devices to establish a tension-rotation relationship.

5.2 Connections and Snug Tight: Four methods for joint assembly and tightening are provided for connections. Regardless of the method used, and before beginning work, tests should be administered using a tension calibrator to ensure that the specified pretension will be achieved.

With any of the four described tensioning methods, it is important to install bolts in all holes of the connection and bring them to an intermediate level of tension generally corresponding to snug tight in order to compact the joint. If however, individual bolts are installed and tightened in a single continuous operation, bolts which are tightened first will be subsequently relaxed by the tightening of the adjacent bolts. The total of the forces in all bolts will be reduced which will reduce the slip load. Even after being fully tightened, some thick parts with uneven surfaces may not be in contact over the entire faying surface. This is not detrimental to the performance of the joint. As long as the specified bolt tension is present in all bolts of the completed connection, the clamping force equal to the total of the tensions in all bolts will be transferred at the locations that are in contact and be fully effective in resisting slip through friction.

With all methods, tightening should begin at the most rigidly fixed or stiffest point and progress toward the free edges, both in the initial snugging up and in the final tightening.

5.3 Turn-of-Nut-Tightening: Consistency and reliability using turn-of-the-nut method is dependent upon assuring that the joint is well compacted and all bolts are uniformly tight as a snug tight condition prior to application of the final required partial turn. Under-tightened bolts will result if this procedure is not followed. Reliability is also dependent upon assuring that the turn applied is relative between the bolt and nut. Thus, the element not turned in tightening should be prevented from rotating while the required degree of turn is applied to the turned element. Reliability and inspectability of the method may be improved by having the outer face of the nut match-marked to the protruding end of the bolt after the joint has been snug tightened but prior to final tightening. Such marks may be applied by the wrench operator using a crayon or dab of paint. Such marks in their relatively displaced position after tightening will afford the inspector a means for noting the rotation that was applied.

Problems with turn-of-nut tightening have been encountered with hot-dip galvanized bolts. In some cases, the problems have been attributed to especially effective lubricant applied by the manufacturer to assure that bolts from stock will meet the material specification requirements without the need for relubricating and retesting. Job site tests in the tension-indicating device demonstrated that the lubricant reduced the coefficient of friction between the bolt and nut to the degree that "the full effort of a man using an ordinary spud wrench" to snug tighten the joint actually induced the full required tension. Also, because the nuts could be turned by application of lower torque than normally expected with non-galvanized bolts, they were erroneously judged improperly tightened by the inspector. Research confirms that lubricated high-strength bolts may require only one-half as much torque to induce the specified tension. In other cases of problems with hot-dip galvanized bolts, the absence of lubrication or lack of proper overtapping caused seizing of the nut and bolt threads which resulted in twist failure of the bolt at low or no tension. For such situations, use of a tension indicating device and the fasteners being installed may be helpful in establishing either the need for lubrication or alternate criteria for snug tight at about one-half the tension required by Table 10.17A.

Because reliability of the method is independent of the presence or absence of washers, washers are not required except for oversize and slotted holes in the outer ply. In the absence of washers, testing after the fact using a torque wrench method is highly unreliable. That is, the turn-of-nut method of installation, properly applied, is more reliable and consistent than the testing method. The best method for inspection of the method is for the inspector to observe the required job site confirmation testing of the fasteners and the method to be used followed by monitoring of the work in progress to assure that the method is routinely properly applied.

Appendix A3
Procedure for Installation and Tightening of High-Strength Fasteners
Calibrated Wrench Method

1.0 BOLTED PARTS AND GENERAL PROVISIONS

1.1 Material within the bolt grip will be steel with no compressible material.

1.2 Slope of surface shall not exceed 1:20. Correct with hardened beveled washers.

1.3 All surfaces free of loose scale, dirt or other foreign material.

1.4 Uncoated joints shall have no paint, including overspray, in the connection area.

1.5 Painted joints shall be blast cleaned and coated with an approved paint. Joints shall not be assembled until paint has cured for the minimum time used in paint qualification testing.

1.6 Galvanized joints shall be roughened by hand wire brushing prior to assembly.

1.7 All fastener components shall be properly lubricated and protected from contamination, dirt and moisture.

1.8 Hardened washers are required under the turned element on all fasteners. Special washers may be required for oversized or slotted holes. See specifications.

1.9 Tightening may be done by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. Impact wrenches, if used, shall be of adequate capacity and sufficiently supplied with air to perform the required tightening of each bolt in approximately 10 seconds.

2.0 WRENCH CALIBRATION

2.1 Equipment required:

2.1.1 Calibrated bolt tension measuring device.

2.1.2 Spacers and/or washers with proper hole size to adjust bolt length in tension measuring device.

2.1.3 Rigid mounting for bolt tension calibrator.

2.1.4 Wrenches, either adjustable impact or manual torque, to be used to install fasteners in the structure.

2.1.5 Appropriate supply of properly sized, uncoated, lot identified Direct Tension Indicating washers (DTIs) which meet the requirements of ASTM F-959. See paragraph 2.4.

2.1.6 Suitable tapered tip flat feeler gauges Range 0.005 inches to 0.030 inches in 0.001 inch increments.

2.1.7 Rigidly mounted steel plate with round hole 1/16 inch over nominal size of bolts to be installed in structure. Can utilize holes in structural steel members to be erected.

2.1.8 Adequate supply of hex head HS bolts, nuts and washers to calibrate DTIs. See paragraph 2.4.1.

2.2 Frequency of Calibration: Each installation wrench shall be calibrated at least once each working day for each bolt diameter, length and grade using fastener assemblies that are being installed in the work. Wrenches shall be recalibrated when significant difference is noted in the surface condition or level of lubrication of the bolt threads, nuts or washers.

2.3 Calibration Procedure: Long bolts shall be of sufficient length so that when installed in the tension measuring device, with a hardened washer under the turned element, at least three (3) full threads are exposed between the nut face and the underside of the bolt head when the end of the bolt is at least flush with the outside face of the nut.

2.3.1 Select three (3) bolt, nut and washer assemblies from each diameter, length and grade for which each individual installation wrench is to be calibrated.

2.3.2 Install each bolt, nut and washer assembly into the tension measuring device and install sufficient spacers and/or washers so that at least three (3), but no more than five (5) full threads, are exposed between the nut face and the underside of the bolt head. The element (nut or bolt head) turned during calibration must be the same as to be turned in the work. A hardened washer must be in place under the turned element.

2.3.3 Tighten each assembly using the snug tightening procedure which will be used to snug tight the fasteners in the work. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. Assure the proposed snug tightening procedure does not produce more than 50% of required fastener tension as specified by Table 10.17A below. If so, revise snug tightening procedure.

TABLE 10.17A - REQUIRED FASTENER TENSION (Kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	12	19	28	39	51	56	71	85	103
M253 (A490)	15	24	35	49	64	80	102	121	148

2.3.4 When the calibrated installation wrench is to be an adjustable impact wrench, each of the three (3) assemblies shall be tightened further and the wrench adjusted or set to cut-out at not less than the minimum tension as shown below. Wrench setting for final installation tightening shall be the average of the three (3) tests.

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

2.3.5 When the calibrated installation wrench is to be a manual torque wrench, each of the three (3) assemblies shall be tightened further and the torque noted which was required to induce the bolt tension as specified in paragraph 2.3.4 above. Torque shall be measured with the turned element in motion. The minimum torque used for final installation tightening shall be the average of the three (3) tests.

2.4 Calibration Procedure - Short Bolts - Short bolts are defined as those lengths which are too short to meet the criteria for long bolts as described in paragraph 2.3.

2.4.1 DTI Calibration - Wrenches to be used to install short bolts may be calibrated using DTIs. However, DTIs must first be calibrated as follows:

2.4.1.1 Select three (3) DTIs of each diameter from the same lot as identified on shipping container.

2.4.1.2 Using appropriate length bolt, nut and flat washer of same diameter as DTI, install DTI under bolt head against face plate of tension calibrator. Protrusions on DTI must bear on head of bolt.

2.4.1.3 Install appropriate adapter in back of tension calibrator to allow flat washer and nut to be installed. Use shims or flat washers to position three (3) to five (5) full threads between face of nut and underside of bolt head.

2.4.1.4 Tighten nut while holding bolt head with a suitable wrench to induce the bolt tension as shown below:

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

2.4.1.5 Using the feeler gauges, measure and record the opening between the DTI face and the underside of the bolt head at each location between the protrusions. The number of protrusions will vary from four (4) to eight (8) depending upon the nominal size of the DTI. Average the measurements for each DTI.

2.4.1.6 Average the results from the three (3) DTIs. The resulting number becomes the DTI calibration to be used to calibrate wrenches for installation of short bolts of the same diameter as the DTI.

2.4.2 Select three (3) bolt, nut and washer assemblies from each diameter, length and grade for which each individual installation wrench is to be calibrated. Also select a DTI from the calibrated lot for each bolt assembly.

2.4.3 Install each bolt nut and washer assembly into the proper steel plate (See 2.1.7) with the DTI under the bolt head and using sufficient spacers and/or washers so that at least three (3) but not more than five (5) full threads are exposed between the nut face and the underside of the bolt head.

2.4.4 With a wrench holding the bolt head, tighten each assembly by turning the nut to obtain a snug tight condition. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using or ordinary spud wrench. See paragraph 2.3.3.

2.4.5 When the calibrated installation wrench is to be an adjustable impact wrench, each of the three (3) assemblies shall be tightened further until the average clearance under the DTI is equal to the value obtained during DTI calibration. See paragraph 2.4.1.6. The wrench shall be adjusted or set to cut-out at not less than the DTI calibration clearance.

2.4.6 When the calibrated installation wrench is to be a manual torque wrench, each of the three (3) assemblies shall be tightened further, with the torque wrench, until the average clearance under the DTI is equal to the value obtained during DTI calibration. See paragraph 2.4.1.6. The torque required to produce this DTI clearance shall be recorded. Torque shall be measured with the nut in motion. The minimum torque used for final installation tightening shall be the average of the three (3) tests.

2.4.7 DTIs used to calibrate wrenches must be utilized in the same position on the fastener assembly as when they were calibrated on the bolt tension calibrator. Case discussed in paragraph 2.4 is DTI under bolt head, turn nut to tighten. This DTI calibration procedure could also be used to calibrate wrenches where the DTI was under the nut and the bolt head was turned. Wrenches can not be calibrated nor can DTIs be calibrated when the DTI is placed under the turned element.

3.0 SNUG TIGHTENING PROCEDURE

3.1 Bolts shall be installed in all holes of the connection with a hardened washer under the turned element and brought up to a snug tight condition.

3.2 Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. The snug tightening procedure used in the work shall be the same snug tightening procedure used when conducting the WRENCH CALIBRATION in paragraph 2.3.3 and 2.4.4.

3.3 Snug tightening shall progress systematically from the most rigid part of the connection to the free edges. Start the pattern near the end of each member being spliced at the center of the pattern and work toward all edges of the splice plate.

3.4 Following this initial snug tightening, all bolts in the joint shall again be systematically tightened as necessary using a similar pattern until all bolts are simultaneously snug tight and the connection is fully compacted.

4.0 FINAL CALIBRATED WRENCH TIGHTENING

4.1 Following the snug tightening operation, all bolts in the connection shall be fully tightened by the calibrated wrench, either air impact or manual torque which has been calibrated in accordance with paragraph 2.0.

4.2 Tightening shall progress systematically from the most rigid part of the joint to its free edges. The calibrated wrench shall be returned to "touch-up" previously tightened fasteners which may have been relaxed as a result of subsequent tightening of adjacent bolts until all fasteners are tightened to the prescribed amount.

4.3 Impact wrenches shall be operated until the wrench cuts-out at the setting established by calibration in paragraph 2.3.4 or 2.4.5. Manual torque wrenches shall be used to tighten the fasteners to the torque determined by calibration in paragraph 2.3.5 or 2.4.6. Torque is always measured with the turned element in motion.

4.4 It shall be verified during actual installation in the assembled steelwork that the wrench adjustment selected by the calibration does not produce a nut or bolt head rotation from snug tight greater than that permitted in the following table 10.17B.

TABLE 10.17B - NUT ROTATION FROM SNUG TIGHT

Bolt Length	Both Faces Normal	One Face Normal -- One Face Sloped Not More Than 1:20	Both Faces sloped Not More Than 1:20
4 x dia. or less	1/3 turn	1/2 turn	2/3 turn
Greater than 4 but no more than 8 x bolt dia.	1/2 turn	2/3 turn	5/6 turn
Greater than 8 x bolt dia. not exceeding 12x	2/3 turn	5/6 turn	1 turn

5.0 COMMENTARY

5.1 Tension Calibrating Devices: At the present time, there is no known economical means for determining the tension in a bolt that has previously been installed in a connection. The actual tension in a bolt installed in a tension calibrator (hydraulic tension indicating device) is directly indicated by the dial of the device, provided the device is properly calibrated. Such a device is an economical and valuable tool that should be readily available whenever high-strength bolts are to be tensioned to the specified pretension. Although each element of a fastener assembly may conform to the minimum requirements of their separate material specifications, their compatibility in an assembly or the need for lubrication can only be assured by testing of the assembly. Hence, such devices are important for confirming the complete fastened assembly as it will be used with the method or tightening to assure the suitability of bolts and nuts, including lubrication, and the adequacy of impact wrenches and/or air pressure, to provide the specified bolt tension.

Testing before start of installation of fasteners in the work will identify potential sources of problems including, but not necessarily limited to, the need for lubrication to prevent failure of bolts by combined high torque with tension, under strength assemblies due to improper marking or heat treatment or quality control of fasteners, excessive overtapping of hot-dip galvanized nuts, improper use of selected installation method by the bolting crews and/or improper or unreliable inspection technique by the inspectors. Such devices are essential to the confirmation testing of fasteners different from AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) bolts,when approved by the Engineer of Record, and direct tension indicators. They are also essential to the specified procedure for the calibrated wrench method of installation, as well as for confirmation demonstration of proper use of any method by the bolting crews. They are essential for the specified procedure for arbitration inspection. They are the only known economically available tool for field use for determining realistic torque to tension relationships for given fastener assemblies.

Hydraulic tension calibrating devices capable of indicating bolt tension undergo a slight deformation under load. Hence the nut rotation corresponding to a given tension reading may be somewhat larger than it would be if the same bolt were tightened against a solid steel abutment.

Stated differently, the reading of the calibrating device tends to under estimate the tension which a given rotation of the turned element would induce in a bolt in an actual joint. This should be borne in mind when using such devices to establish a tension-rotation relationship.

5.2 Connections and Snug Tight: Four methods for joint assembly and tightening are provided for connections. Regardless of the method used, the tension calibrator should be demonstrated prior to the commencement of work using the fasteners that the crews will use to provide the specified pretension.

With any of the four described tensioning methods, it is important to install bolts in all holes of the connection and bring them to an intermediate level of tension generally corresponding to snug tight in order to compact the joint. If however, individual bolts are installed and tightened in a single continuous operation, bolts which are tightened first will be subsequently relaxed by the tightening of the adjacent bolts. The total of the forces in all bolts will be reduced which will reduce the slip load. Even after being fully tightened, some thick parts with uneven surfaces may not be in contact over the entire faying surface. This is not detrimental to the performance of the joint. As long as the specified bolt tension is present in all bolts of the completed connection, the clamping force equal to the total of the tensions in all bolts will be transferred at the locations that are in contact and be fully effective in resisting slip through friction.

With all methods, tightening should begin at the most rigidly fixed or stiffest point and progress toward the free edges, both in the initial snugging up and in the final tightening.

5.3 Calibrated Wrench Method: Research has demonstrated that scatter in induced tension is to be expected when torque is used as an indirect indicator of tension. Numerous variables, which are not related to tension, effect torque. For example, the finish and tolerance on bolt threads and on the nut threads; the fact that the bolt and nut may not be produced by the same manufacturer; the degree of lubrication; the job site conditions contributing to dust and dirt or corrosion on the threads; the friction that exists to varying degrees between the turned element and the supporting surface; the variability of the air pressure on the torque wrenches due to length of air lines or number of wrenches operating from the same source; the condition and lubrication of the wrench which may change within a work shift and other factors all bear upon the effectiveness of the calibrated torque wrench to induce tension.

The calibrated wrench method is the least reliable of all methods of installation and many costly controversies have occurred. It is suspected that short cut procedures and failure to conscientiously follow the specification requirements were probably involved in many instances in the calibrated wrench method of installation. It is recognized, however, that if the calibrated wrench method is implemented without short cuts there will be a ninety percent assurance that the tensions specified in Table 10.17A will be equaled or exceeded.

To provide greater assurance of proper tensioning the specification has been modified to require better control. Wrenches must be calibrated daily for each diameter and grade of bolt. Hardened washers must be used. Fasteners must be protected from dirt and moisture at the job site. To further achieve reliable results, attention should be given to the control, insofar as it is practical, of those controllable factors which contribute to variability. For example, bolts and nuts should be purchased from reliable manufacturers with a record of good quality control to minimize the variability of the fit. Bolts and nuts should be adequately and uniformly lubricated.

Appendix A4
Procedure for Installation and Tightening of High-Strength Fasteners
Alternate Design Fasteners

1.0 BOLTED PARTS AND GENERAL PROVISIONS

1.1 Material within the bolt grip will be steel with no compressible material.

1.2 Slope of surface shall not exceed 1:20. Correct with hardened beveled washers.

1.3 All surfaces free of loose scale, dirt or other foreign material.

1.4 Uncoated joints shall have no paint, including overspray, in the connection area.

1.5 Painted joints shall be blast cleaned and coated with an approved paint. Joints shall not be assembled until paint has cured for the minimum time used in paint qualification testing.

1.6 Galvanized joints shall be roughened by hand wire brushing prior to assembly.

1.7 All fastener components shall be properly lubricated and protected from contamination, dirt and moisture.

1.8 Hardened washers may be required under the turned element when specified by the fastener manufacturer. Special washers may be required for oversized or slotted holes. See specifications.

2.0 TENSION VERIFICATION TESTING

2.1 Equipment required:

2.1.1 Calibrated bolt tension measuring device.

2.1.2 Spacers and/or washers with proper hole size to adjust bolt length in tension measuring device.

2.1.3 Rigid mounting for bolt tension calibrator.

2.1.4 Wrenches to install fasteners in the structure.

2.1.5 Appropriate supply of properly sized, uncoated, lot identified Direct Tension Indicating washers (DTIs) which meet the requirements of ASTM F-959. See paragraph 2.4.

2.1.6 Suitable tapered tip flat feeler gauges Range 0.005 inches to 0.030 inches in 0.001 inch increments.

2.1.7 Rigidly mounted steel plate with round hole 1/16 inch over nominal size of bolts to be installed in structure. Can utilize holes in structural steel members to be erected.

2.1.8 Adequate supply of hex head HS bolts, nuts and washers to calibrate DTIs. See paragraph 2.4.1.2.

2.2 Testing Frequency: As a minimum, three (3) fastener assemblies shall be checked from each fastener length, diameter and grade. The testing should be done immediately prior to start of installation of the fasteners in the work. Fasteners should be retested when any significant difference is noted in the surface condition or level of lubrication of the fastener threads, nuts or washers.

2.3 Testing Procedure: Long bolts are defined as bolts of sufficient length so that when installed in the tension measuring device, with a hardened washer (when required), at least three (3) full threads are exposed between the nut face and the underside of the bolt head when the end of the bolt is at least flush with the outside face of the nut.

2.3.1 Select three (3) fastener assemblies from each diameter, length and grade.

2.3.2 Install each fastener assembly into the tension measuring device and install sufficient spacers and/or washers so that at least three (3) but no more than five (5) full threads are exposed between the nut face and the underside of the bolt head. The fastener manufacturer's installation procedure shall be followed for installation of bolts in the calibration device and in all connections.

2.3.3 Tighten each assembly using the snug tightening procedure which will be used to snug tight the fasteners in the work. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. Assure the proposed snug tightening procedure does not produce more than 50% of required fastener tension as specified by Table 10.17A below. If so, revise snug tightening procedure.

TABLE 10.17A - REQUIRED FASTENER TENSION (Kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	12	19	28	39	51	56	71	85	103
M253 (A490)	15	24	35	49	64	80	102	121	148

2.3.4 Following the fastener manufacturer's procedure, further tighten each of the three (3) assemblies until the final twist-off of the control or indicator element. Each assembly must indicate a minimum tension as shown below.

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

2.4 Testing Procedure: Short bolts are defined as those lengths which are too short to meet the criteria for long bolts as described in paragraph 2.3.

2.4.1 DTI Calibration : Proper fastener tension for short bolts may be verified using DTIs. However, DTIs must first be calibrated as follows:

2.4.1.1 Select three (3) DTIs of each diameter from the same lot as identified on shipping container.

2.4.1.2 Using appropriate length conventional hex head bolt, nut and flat washer of same diameter as DTI, install DTI under bolt head against face plate of tension calibrator. Protrusions on DTI must bear on head of bolt.

2.4.1.3 Install appropriate adapter in back of tension calibrator to allow flat washer and nut to be installed. Use shims or flat washers to position three (3) to five (5) full threads between face of nut and underside of bolt head.

2.4.1.4 Tighten nut while holding bolt head with a suitable wrench to induce the bolt tension as shown below:

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	13	20	29	41	54	59	75	89	108
M253 (A490)	16	25	37	51	67	84	107	127	155

2.4.1.5 Using the feeler gauges, measure and record the opening between the DTI face and the underside of the bolt head at each location between the protrusions. The number of protrusions will vary from four (4) to eight (8) depending upon the nominal size of the DTI. Average the measurements for each DTI.

2.4.1.6 Average the results from the three (3) DTIs. The resulting number becomes the DTI calibration to be used to verify proper tension in the short bolts.

2.4.2 Select three (3) fastener assemblies from each diameter, length and grade of short bolts. Also select a DTI from the calibrated lot for each fastener assembly.

2.4.3 Install each fastener assembly into the proper steel plate (See 2.1.7) with the DTI under the bolt head and using sufficient spacers and/or washers so that at least three (3) but not more than five (5) full threads are exposed between the nut face and the underside of the bolt head.

2.4.4 Tighten each assembly to obtain a snug tight condition. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using or ordinary spud wrench. See paragraph 2.3.3.

2.4.5 Using equipment and procedures recommended by the fastener manufacturer, each of the three (3) assemblies shall be tightened further until the final twist-off of the control or indicator element.

2.4.6 Using the feeler gauges, measure and record the opening between the DTI face and the underside of the bolt head at each location between the protrusions. The number of protrusions will vary from four (4) to eight (8) depending upon the nominal size of the DTI. Average the measurements for each DTI.

2.4.7 Average the results from the three (3) DTIs for each diameter, length and grade. This average clearance must be equal to or less than the DTI clearance determined in paragraph 2.4.1.6.

3.0 SNUG TIGHTENING PROCEDURE

3.1 Fasteners shall be installed in all holes of the connection and brought up to a snug tight condition. Washers are required if they were used in the Tension Verification Testing.

3.2 Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be obtained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. The snug tightening procedure used in the work shall be the same snug tightening procedure used when conducting the Tension Verification Testing in paragraph 2.3.3 and 2.4.4.

3.3 Snug tightening shall progress systematically from the most rigid part of the connection to the free edges. Start the pattern near the end of each member being spliced at the center of the pattern and work toward all edges of the splice plate.

3.4 Following this initial snug tightening, all bolts in the joint shall be again systematically tightened as necessary using a similar pattern until all bolts are simultaneously snug tight and the connection is fully compacted.

4.0 FINAL TIGHTENING

4.1 Following the snug tightening operation, all fasteners shall be further tightened until the final twist-off of the control or indicator element. All tightening shall be done using equipment and procedures recommended by the fastener manufacturer.

4.2 Tightening shall progress systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final twist-off of the control or indicator element of individual fasteners.

5.0 COMMENTARY

5.1 Tension Calibrating Devices: At the present time, there is no known economical means for determining the tension in a bolt that has previously been installed in a connection. The actual tension in a bolt installed in a tension calibrator (hydraulic tension indicating device) is directly indicated by the dial of the device, provided the device is properly calibrated. Such a device is an economical and valuable tool that should be readily available whenever high-strength bolts are to be tensioned to the specified pretension. Although each element of a fastener assembly may conform to the minimum requirements of their separate material specifications, their compatibility in an assembly or the need for lubrication can only be assured by testing of the assembly. Hence, such devices are important for confirming the complete fastened assembly as it will be used with the method of tightening to assure the suitability of bolts and nuts, including lubrication, and the adequacy of impact wrenches and/or air pressure, to provide the specified bolt tension.

Testing before start of installation of fasteners in the work will identify potential sources of problems including, but not necessarily limited to, the need for lubrication to prevent failure of bolts by combined high torque with tension, under strength assemblies due to improper marking or heat treatment or quality control of fasteners, excessive overtapping of hot-dip galvanized nuts, improper use of selected installation method by the bolting crews and/or improper or unreliable inspection techniques by inspectors. Such devices are essential to the confirmation testing of fasteners different from AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) bolts,when approved by the Engineer of Record, and direct tension indicators. They are also essential to the specified procedure for the calibrated wrench method of installation, as well as for confirmation demonstration of proper use of any method by the bolting crews. They are essential for the specified procedure for arbitration inspection. They are the only known economically available tool for field use for determining realistic torque to tension relationships for given fastener assemblies.

Hydraulic tension calibrating devices capable of indicating bolt tension undergo a slight deformation under load. Hence, the nut rotation corresponding to a given tension reading may be somewhat larger than it would be if the same bolt were tightened against a solid steel abutment.

Stated differently, the reading of the calibrating device tends to underestimate the tension which a given rotation of the turned element would induce in a bolt in an actual joint. This should be borne in mind when using such devices to establish a tension-rotation relationship.

5.2 Connections and Snug Tight: Four methods for joint assembly and tightening are provided for connections. Regardless of the method used, and before beginning work, test should be administered using a tension calibrator to ensure that specified pretension will be achieved.

With any of the four described tensioning methods, it is important to install bolts in all holes of the connection and bring them to an intermediate level of tension generally corresponding to snug tight in order to compact the joint. If however, individual bolts are installed and tightened in a single continuous operation, bolts which are tightened first will be subsequently relaxed by the tightening of the adjacent bolts. The total of the forces in all bolts will be reduced which will reduce the slip load. Even after being fully tightened, some thick parts with uneven surfaces may not be in contact over the entire faying surface. This is not detrimental to the performance of the joint. As long as the specified bolt tension is present in all bolts of the completed connection, the clamping force equal to the total of the tensions in all bolts will be transferred at the locations that are in contact and be fully effective in resisting slip through friction.

With all methods, tightening should begin at the most rigidly fixed or stiffest point and progress toward the free edges, both in the initial snugging up and in the final tightening.

5.3 Installation of Alternate Design Fasteners: When high-strength bolts with mechanical properties equivalent to AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) but with different geometry which is intended to provide automatic control of installed bolt tension are used, the provision of this article shall apply. The bolts currently being used of this general type involve a splined end extending beyond the threaded portion of the bolt which is gripped by a specially designed wrench chuck which provides a means for turning the nut relative to the bolt. While such bolts are subject to many of the variables affecting torque mentioned in the calibrated wrench procedure, they are produced and shipped by the manufacturers as a nut-bolt assembly under good quality control which apparently minimizes some of the negative aspects of the torque controlled process.

While these alternate design fasteners have been demonstrated to consistently provide tension in the fastener meeting the requirements of Table 10.17A, in controlled tests in tension indicating devices, it must be recognized that the fastener may be misused and provide results as unreliable as those with other methods. They must be used in the as delivered clean lubricated condition. The requirements of this Specification as well as the installation requirements of the manufacturer's specification must be adhered to.

As with other methods, a representative sample of the bolts to be used should be tested to assure that they do, in fact, when used in accordance with manufacturer's instructions, provide tension as specified in Table 10.17A. In the actual joints, bolts must be installed in all holes of a connection and all fasteners tightened to an intermediate level of tension adequate to pull all material into contact. Only after this has been accomplished should the fasteners be fully tensioned in a systematic manner and the splined end sheared off. The sheared off splined end merely signifies that at some time the bolt has been subjected to a torque adequate to cause the shearing. If the fasteners are installed and tensioned in a single continuous operation, they will give a misleading indication to the inspector that the bolts are properly tightened. Therefore, the only way to inspect these fasteners with assurance is to observe the job-site testing of the fasteners and installation procedure and then monitor the work while in progress to assure that the specified procedure is routinely followed.

Appendix A5
Procedure for Inspection of High-Strength Fasteners Installation

1.0 PRE-INSTALLATION INSPECTION

1.1 The Engineer shall check the marking, surface condition and storage of bolts, nuts and washers and the faying surfaces of joints for compliance with the specification requirements.

1.2 When faying surfaces of slip critical joints are specified to be painted, the Engineer will assure that only tested and qualified coatings are applied to the members. When the painting is being done at the location where the joints are to be assembled, the Engineer will assure the coating has cured for the minimum time used in qualification testing before assembly.

1.3 The Engineer must verify that all bolt tension calibrators and torque wrenches have been calibrated within the last year and test certificates are available.

1.4 The Engineer shall witness all Rotational Capacity (R-C) tests performed at the fastener installation site to assure the tests are properly conducted, at the required frequency and test results are in compliance with the specifications.

1.5 The Engineer shall witness all wrench calibration, turn-of-nut verification testing, tension verification testing and direct tension indicator (DTI) calibration required by the specification requirements to assure the tests are properly conducted at the required frequency.

1.6 The Engineer will assure that each member of the bolting crew(s) is familiar with the procedural requirements for the tightening method selected by the contractor. Each bolting crew member must also fully understand the procedure for snug tightening the joint and fasteners, and should have demonstrated this knowledge by tightening a fastener in a bolt tension calibrator.

2.0 INSPECTION DURING INSTALLATION

2.1 The Engineer must constantly monitor the surface condition of fasteners in order to prevent accumulation of dirt or rust and to detect any change in the level of lubrication.

2.2 Allow only as many fasteners as are anticipated to be installed and tightened during a work shift to be removed from protective storage. Fasteners not used shall be returned to protected storage at the end of the shift.

2.3 At any time during the erection process when the Engineer suspects there may have been a change in the level of lubrication of the fasteners he should immediately require the Rotational Capacity (R-C) test to be re-conducted as well as all calibration and verification testing listed in Paragraph. 1.5.

2.4 The Engineer shall monitor the installation of the fasteners in the work to assure that the selected installation method, as demonstrated in the initial testing to provide the specified tension, is routinely properly applied. This monitoring shall also include verification that all plies of connected material have been drawn together and the procedure for snug tightening has been followed.

3.0 INSPECTION OF COMPLETED INSTALLATION (ARBITRATION INSPECTION)

In addition to the requirements of paragraph. 1.0 and 2.0, inspection of completed joints is required. The following inspection procedure shall be used unless a different procedure is specified in the contract documents.

3.1 Equipment required:

3.1.1 Calibrated bolt tension measuring device.

3.1.2 Spacers and/or washers with proper hole size to adjust bolt length in tension measuring device.

3.1.3 Rigid mounting for bolt tension calibrator.

3.1.4 Calibrated torque wrench, either dial type or other design which can be adjusted to give an indication of actual torque.

3.1.5 Appropriate supply of properly sized, uncoated, lot identified Direct Tension Indicating washers (DTIs), which meet the requirements of ASTM F-959. See paragraph 3.5.3.1.

3.1.6 Suitable tapered tip flat feeler gauges, range 0.005 inches to 0.030 inches in 0.001 inch increments.

3.1.7 Rigidly mounted steel plate with round hole 1/16 inch over nominal size of bolts installed in structure. Can utilize holes in structural steel members.

3.1.8 Adequate supply of hex head HS bolts, nuts and washers to calibrate DTIs. See paragraph 3.5.3.1

3.2 Inspection Responsibility - Either the Engineer or the Contractor, in the presence of the Engineer, at the Engineer's option, shall perform the inspection of completed joints using an inspection wrench (torque wrench).

3.3 The governing specifications for installation of high strength fasteners, or this inspection procedure do not recognize standard torques determined from tables or from formulas which are assumed to relate torque to tension in the fastener. Testing and inspection using such standard torques shall not be considered valid.

3.4 Frequency of Inspection - Each connection in question in the structure shall be inspected by applying, in the tightening direction, the inspecting wrench and it's job inspection torque to 10 percent of the fasteners, but not less than 2 fasteners selected at random.

3.5 Determination of Job Inspection Torque

3.5.1 The job inspection torque shall be determined at least daily for each diameter, length and grade for which inspection will be conducted on that day.

3.5.2 Job Inspection Torque: Long bolts are defined as bolts of sufficient length so that when installed in the tension measuring device, at least three (3) full threads are exposed between the nut face and the underside of the bolt head when the end of the bolt is at least flush with the outside face of the nut.

3.5.2.1 Select five (5) bolts, nuts and washers, if washers were used under the turned element during installation in the structure, from each diameter, length and grade for which each individual inspection wrench is to be calibrated. The samples selected must be representative of the fasteners used in the work and should be from the same manufacturer's lot if at all possible. When the fasteners to be inspected with the inspection wrench have been installed in the structure for any significant length of time and have been exposed to the elements, the samples to be used to calibrate the inspection wrench should be selected from the fasteners in the work.

3.5.2.2 Install each bolt, nut and washer (when required) assembly into the tension measuring device and install sufficient spacers and/or washers so that at least three (3) but no more than five (5) full threads are exposed between the nut face and the underside of the bolt head. The element (nut or bolt head) turned during calibration must be the same that was turned during installation of the fasteners in the structure. Separate determinations of job inspection torque must be made if both methods were used in the work.

3.5.2.3 Tighten each assembly by any convenient means to an initial condition equal to approximately the following: (kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	2	3	4	6	8	8	11	13	15
M253 (A490)	2	4	5	7	10	12	15	18	22

3.5.2.4 Then tighten each assembly by any convenient means to the following tension: (kips)

TABLE 10.17A - REQUIRED FASTENER TENSION (Kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	12	19	28	39	51	56	71	85	103
M253 (A490)	15	24	35	49	64	80	102	121	148

3.5.2.5 Tightening beyond the initial condition must not produce greater rotation of the turned element than that shown below:

BOLT LENGTH (Inches)	ROTATION
4 x dia. or less	1/2 turn
Greater than 4 but no more than 8 x bolt dia.	3/4 turn
Greater than 8 x bolt dia. not exceeding 12 x	1 turn

3.5.2.6 The inspection wrench shall then be applied to each of the five (5) tightened bolts and the torque necessary to turn the nut or bolt head 5 degrees (approximately 1 inch in a 12 inch radius) in the tightening direction shall be determined. From a practical standpoint this is the torque necessary to just start rotation of the turned element. Record all five (5) torque determinations.

3.5.2.7 The job inspection torque shall be taken as the average of the three (3) remaining values after rejecting the high and low values.

3.5.3 Job Inspection Torque - Short Bolts - Short bolts are defined as those lengths which are too short to meet the criteria for long bolts as defined in paragraph 3.5.2.

3.5.3.1 DTI Calibration - Inspection wrenches to be used to inspect short bolts must be calibrated to determine "job inspection torque" using DTIs. However, DTIs must first be calibrated as follows:

3.5.3.1.1 Select three (3) DTIs of each diameter from the same lot as identified on the shipping container. See paragraph 3.1.5.

3.5.3.1.2 Using appropriate length bolt, nut and flat washer of same diameter as DTI, (See paragraph 3.1.8) install DTI under bolt head against face plate of tension calibrator. Protrusions on DTI must bear on head of bolt.

3.5.3.1.3 Install appropriate adapter in back of tension calibrator to allow flat washer and nut to be installed. Use shims or flat washers to position three (3) to five (5) full threads between face of nut and underside of bolt head.

3.5.3.1.4 Tighten nut while holding bolt head with a suitable wrench to induce the approximate bolt tension as shown below:

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
M164 (A325)	2	3	4	6	8	8	11	13	15
M253 (A490)	2	4	5	7	10	12	15	18	22

3.5.3.1.5 Using the feeler gauges, measure and record the opening between the DTI face and the underside of the bolt head at each location between the protrusions. The number of protrusions will vary from four (4) to eight (8) depending upon the nominal size of the DTI. Average the measurements for each DTI. Record the average value.

3.5.3.1.6 Further tighten the nut while holding bolt head with a suitable wrench to induce the bolt tension as shown below:

TABLE 10.17A - REQUIRED FASTENER TENSION (kips)

Bolt Dia. (in)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2

M164 (A325)	12	19	28	39	51	56	71	85	103
M253 (A490)	15	24	35	49	64	80	102	121	148

3.5.3.1.7 Using the feeler gauges, measure and record the opening between the DTI face and the underside of the bolt head at each location between the protrusions. The number of protrusions will vary from four (4) to eight (8) depending upon the nominal size of the DTI. Average the measurements for each DTI. Record the average value.

3.5.3.1.8 Repeat steps in paragraph 3.5.3.1.2 thru 3.5.3.1.7 for the other two (2) DTIs. Average the three (3) values obtained for each DTI in step 3.5.3.1.5. This opening becomes the DTI calibration to be used to establish the "initial condition tension" as used in paragraph 3.5.2.3.

3.5.3.1.9 Average the three (3) values obtained for each DTI in step 3.5.3.1.7. This opening becomes the DTI calibration to be used to establish the bolt tension as used in paragraph 3.5.2.4.

3.5.3.2 Select five (5) bolts, nuts and washers, if washers were used under the turned element during installation in the structure, from each diameter, length and grade for which each individual inspection wrench is to be calibrated. The samples selected must be representative of the fasteners used in the work and should be from the same manufacturer's lot if at all possible. When the fasteners to be inspected with the inspection wrench have been installed in the structure for any significant length of time and have been exposed to the elements, the samples to be used to calibrate the inspection wrench should be selected from the fasteners in the work.

3.5.3.3 Install each bolt, nut and washer (when required) assembly into the proper steel plate (see paragraph 3.1.7) with the DTI under the bolt head and using sufficient spacers and/or washers so that at least three (3) but not more than five (5) full threads are exposed between the nut face and the underside of the bolt head.

3.5.3.4 With a wrench holding the bolt head, tighten each assembly by any convenient means until the DTI clearance is approximately equal to the clearance determined in paragraph 3.5.3.1.8, initial condition tension. Then further tighten the assembly until the DTI clearance is equal to the clearance determined in paragraph 3.5.3.1.9, minimum bolt tension.

3.5.3.5 Tightening beyond the initial condition must not produce greater rotation of the turned element than that shown below:

BOLT LENGTH (Inches)	ROTATION
4 X dia. or less	1/2 turn
Greater than 4 but no more than 8 x bolt dia.	3/4 turn

Greater than 8 x bolt dia. not exceeding 12 x	1 turn

3.5.3.6 The inspection wrench shall then be applied to each of the five (5) tightened bolts and the torque necessary to turn the nut or bolt head 5 degrees (approximately 1 inch in a 12-inch radius) in the tightening direction shall be determined. From a practical standpoint this is the torque necessary to just start rotation of the turned element. Record all five (5) torque determinations.

3.5.3.7 The job inspection torque shall be taken as the average of the three (3) remaining values after rejecting the high and low values.

3.6 Fasteners represented by the samples referenced in paragraph 3.5.2.1 and 3.5.3.2 which have been tightened in the structure shall be inspected by applying, in the tightening direction, the inspecting wrench and it's job inspection torque to 10 percent of the fasteners, but not less than 2 fasteners, selected at random in each connection in question.

3.7 If no nut or bolt head is turned by the application of the job inspection torque, the connection shall be accepted as properly tightened.

3.8 If any nut or bolt is turned by the application of the job inspection torque, all fasteners in the connection shall be tested, and all fasteners whose nut or head is turned by the job inspection torque shall be tightened and reinspected. Alternatively, the fabricator or erector, at his option, may retighten all of the fasteners in the connection and then resubmit the connection for the specified inspection.

4.0 DELAYED VERIFICATION INSPECTION

4.1 The inspection procedures specified in paragraph 3.0 are intended for inspection of bolted connections and verification of pretension at the time of tensioning the joint.

4.2 If verification of fastener tension is required after a passage of a period of time and exposure of the completed joints, the procedures of paragraph 3.0 will provide an indication of fastener tension which is of questionable accuracy.

4.3 Procedures appropriate to the specific situation should be used for verification of bolt tension. This might involve use of the inspection procedure contained in paragraph 3.0, or might require the development and use of alternate procedures.

5.0 COMMENTARY

5.1 Tension Calibrating Devices: At the present time, there is no known economical means for determining the tension in a bolt that has previously been installed in a connection. The actual tension in a bolt installed in a tension calibrator (hydraulic tension indicating device) is directly indicated by the dial of the device, provided the device is properly calibrated. Such a device is an economical and valuable tool that should be readily available whenever high-strength bolts are to be tensioned to the specified pretension. Although each element of a fastener assembly may conform to the minimum requirements of their separate material specifications, their compatability in an assembly or the need for lubrication can only be assured by testing of the assembly. Hence, such devices are important for confirming the complete fastened assembly as it will be used with the method of tightening to assure the suitability of bolts and nuts, including lubrication, and the adequacy of impact wrenches and/or air pressure, to provide the specified bolt tension.

Testing before start of installation of fasteners in the work will identify potential sources of problems including, but not necessarily limited to, the need for lubrication to prevent failure of bolts by combined high torque with tension, under strength assemblies due to improper marking or heat treatment or quality control of fasteners, excessive overtapping of hot-dip galvanized nuts, improper use of selected installation method by the bolting crews and/or improper or unreliable inspection technique by the inspectors. Such devices are essential to the confirmation testing of fasteners different from AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) bolts,when approved by the Engineer of Record, and direct tension indicators. They are also essential to the specified procedure for the calibrated wrench method of installation, as well as for confirmation demonstration of proper use of any method by the bolting crews. They are essential for the specified procedure for arbitration inspection. They are the only known economically available tool for field use for determining realistic torque to tension relationships for given fastener assemblies.

Hydraulic tension calibrating devices capable of indicating bolt tension undergo a slight deformation under load. Hence the nut rotation corresponding to a given tension reading may be somewhat larger than it would be if the same bolt were tightened against a solid steel abutment.

Stated differently, the reading of the calibrating device tends to under estimate the tension which a given rotation of the turned element would induce in a bolt in an actual joint. This should be borne in mind when using such devices to establish a tension-rotation relationship.

5.2 Inspection: It is apparent from the commentary on installation procedures that the inspection procedures giving the best assurance that bolts are properly installed and tensioned is provided by inspector observation of the calibration testing of the fasteners using the selected installation procedure followed by monitoring of the work in progress. This will assure that the procedure which was demonstrated to provide the specified tension is routinely adhered to. When such a program is followed, no further evidence of proper bolt tension should be required.

If testing for bolt tension using torque wrenches is conducted subsequent to the time the work of installation and tightening of bolts is performed, the test procedure is subject to all of the uncertainties of torque controlled calibrated wrench installation. Additionally, the absence of many of the controls necessary to minimize variability of the torque to tension relationship, which are unnecessary for the other methods of bolt installation. These are: use of hardened washers, careful attention to lubrication and the uncertainity of the effect of passage of time and exposure in the installed condition. These all reduce the reliability of the arbitration inspection results. The fact that in many cases it may have to be based upon a job test torque (determined using bolts only assumed to be representative of the bolts in the actual joint being tested or using bolts removed from completed joints) makes the test procedure less reliable than a properly implemented installation procedure it is used to verify. Verification inspection using ultrasonic extensometers is very accurate, but costly and time consuming, and requires that each tested bolt must be loosened to zero tension for calibration. Therefore extensometers should be used for inspection only in the most critical cases.

APPENDIX A6
PROCEDURE FOR VERIFICATION AND INSTALLATION OF HIGH STRENGTH BOLTS WITH DIRECT TENSION INDICATORS (DTIs)

I. Verification of DTI Performance

Verification of DTI performance is required prior to installation of bolts in the work. In bridge work the manufacturers are typically specifying smaller gaps in the spaces between the protrusions on the washer than normally used in other construction and the gap specified for testing in the product specification ASTM F959. The verification test method is used to determine the maximum number of spaces at which a 0.005 inch-tapered feeler gage is refused, does not fit into the space, at a load equal to 1.05 times the required bolt installation tension. This maximum number of refusal spaces is one less than the job installation inspection requirement. In addition, as part of verification test, the DTIs shall be further crushed to a level such that the inspection feeler gage is refused at all spaces between the protrusions of the washer and a visible gap still remaining in at least one space. The load at this minimum gap should not cause permanent inelastic deformation of the fastener. The inelastic deformation is judged by removing the fastener from the test apparatus and turning the nut by hand the full length of the threads on the bolt after the test. If the nut can be turned the full thread length, the DTI minimum gap load requirement is satisfied. The installation verification test shall be performed three times for each fastener rotational capacity lot on the job with the corresponding DTI to be used. If the same R-C lot is to be installed with the DTI in two different positions with respect to the turned element, three tests are required for each position of the DTI. Bolts from R-C lots too short to fit in the tension measuring device shall be tested by tightening in a steel plate to the minimum gap in step 6 and checked in accordance with step 7. The DTI used with the short bolts should be checked in accordance with steps 1 through 5 using a longer bolt in the tension measuring device.

Equipment Required:

1. Calibrated bolt tension measuring device with a special flat insert in place of normal bolt head holding insert. Special insert required to allow access to measure DTI gap.

2. Tapered leaf thickness (feeler) gage, 0.005 inch. Same gage as to be used to inspect the bolts after installation.

3. Bolts, nuts, and standard washers to be used in the work with the DTIs.

4. Impact and manual wrench to tighten bolts. Equipment should be the same as to be used in the work.

Verification Test Procedure: (Test three tests for each R-C lot and position of DTI)

1. Install bolt, nut, DTI, and standard washer (if used) into bolt tension measuring device. Assembly should match that to be used in the work.

2. Snug the bolt to no more than 50% of the required installation tension using the equipment which will be used in the work. Use another wrench on the bolt head to prevent rotation of the head against the DTI if the DTI is to be used under the unturned element.

3. Further tighten bolt to tension listed below (1.05 times the required installation tension of the bolt). Use another wrench on the bolt head to prevent rotation of the head against the DTI if the DTI is to be used under the unturned element. If an impact wrench is used, tighten to a load slightly below the required load and use a manual wrench to attain the required tension. The load indicating needle of the bolt calibrator cannot be read accurately when an impact wrench is used.

Bolt Tension (kips)									
Bolt Dia.(in)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
M164(A325)	13	20	29	41	54	59	75	89	108
M253(A490)	na	na	37	51	67	84	107	127	na

4. Determine and record the number of spaces between the protrusion on the DTI that a 0.005 in. thickness gage is refused. The total number of spaces in the various sizes and grade of DTI's is shown below.

Number of Spaces									
Bolt Dia.(in)	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2
M164(A325)	4	4	5	5	6	6	7	7	8
M253(A490)	na	na	6	6	7	7	8	8	na

5. The number of spaces which the 0.005 in. gage is refused should not exceed the number given in the table below. If the number of spaces exceeds the number in the table, the DTI fails the verification test.

Verification Criteria*					
Number of spaces in washer	4	5	6	7	8
Maximum number of spaces gage is refused	1	2	2	3	3

*If the test is a coated DTI under the turned element, the maximum number of spaces the gage is refused is the number of spaces on the washer minus one.

6. The bolt should be further tightened to the smallest gap to be allowed in the work. Normally, this smallest gap is defined as the gap at all the spaces less than 0.005 inch and not all gaps completely closed. The 0.005 inch-gage is refused at all spaces but a visible gap exists in at least one space. The bolts in this test and in the actual installation should not be installed to a no visible gap condition. The load in the bolt becomes indeterminant when no gap exists. Failure of the bolt due to over tightening may occur when the bolt is tightened beyond complete crushing of the DTI.

7. Remove the bolt from the calibrator and turn the nut on the threads of the bolt by hand. The nut should be able to be turned on the complete length of the threads, excluding the thread runout. If the nut is unable to go the full thread length, the load required for the minimum gap in step 6 is too large. The test must be repeated with a larger minimum gap, for example one space that will accept a 0.005 in. feeler gage, to establish the smallest gap allowed in the work for the fastener rotational capacity lot allowed in the work.

Short Bolts:

Bolts from R-C lots too short to fit in the tension measuring device shall be tested by tightening to the minimum gap in step 6 and checked in accordance with step 7. The DTI used with the short bolt should be checked in accordance with steps 1 through 5 using a longer bolt in the tension measuring device.

II. Installation:

1. The use of a DTI under the unturned bolt head requires that the element bearing against the DTI not turn. Two crew members are required: One to operate the wrench, and the other to prevent turning of the element with the DTI and to monitor the gap. If the DTI is used under the turned element, an additional hardened washer must be used between the turning element and the protrusion on the DTI.

2. Snug the connection to compact the joint. The DTI should be inspected after snugging and the gaps checked. If the number of spaces in which the 0.005 in. gage is refused exceeds the value in the table shown above in step 5 of the verification test, the bolt must be removed and another DTI installed. The bolt should be resnugged.

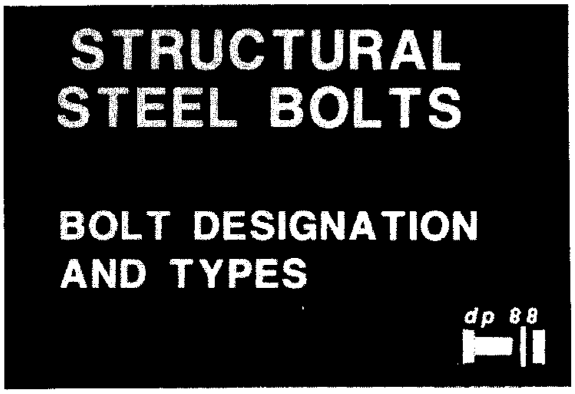
3. Tighten the bolts systematically to the inspection gap. The number of spaces which the 0.005 inch-gage is refused should be equal to or greater then the number shown in the table below. Tightening beyond the minimum gap established above in steps 6 and 7 is not allowed. Bolts which have a DTI with a smaller gap or no gap shall be replaced and the new bolts tightened with a new DTI.

Inspection Criteria*					
Number of spaces in washer	4	5	6	7	8
Minimum number of spaces gage is refused	2	3	3	4	4

*The gage shall be refused in all spaces when a coated DTI is used under the turned element.

APPENDIX B

Definitions and Fastener Behavior



B - 1

STRUCTURAL STEEL BOLTS

M164 (A325) Bolts:

High-Strength Bolt for Structural Steel Joints.

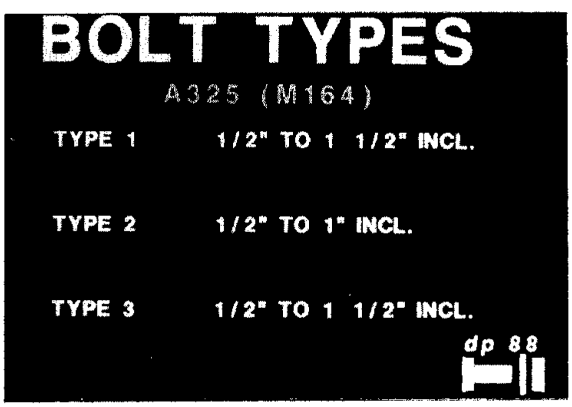
These are heat-treated, quenched, and tempered high-strength bolts made from medium-carbon steel.

B - 2

M253 (A490) Bolts:

Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength.

(These are quenched and tempered high-strength bolts made from alloy steel.)



B - 3

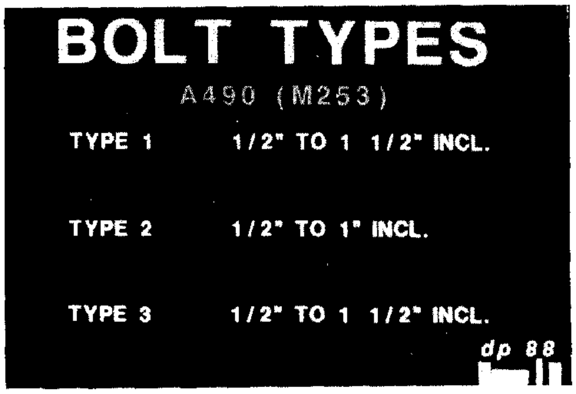
BOLT TYPES

Type 1 - Medium-Carbon Steel

Type 2 - Low-Carbon Martensite Steel (no longer manufactured in U.S. ASTM is considering eliminating this type).

Type 3 - Atmospheric Corrosion Resistant Weathering Characteristic Steel.

Note: AASHTO does not allow less than ⅝-inch diameter bolts.



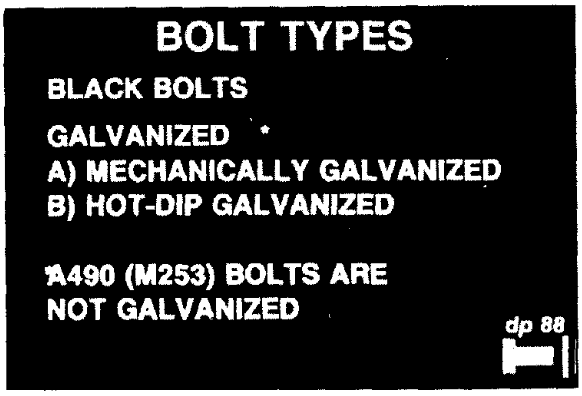
B - 4

A490 (M253) BOLTS

Type 1 - Alloy Steel.

Type 2 - Low-Carbon Martensite Steel (no longer manufactured in U.S., ASTM is considering eliminating this type).

Type 3 - Atmospheric Corrosion Resistant Weathering Steel.



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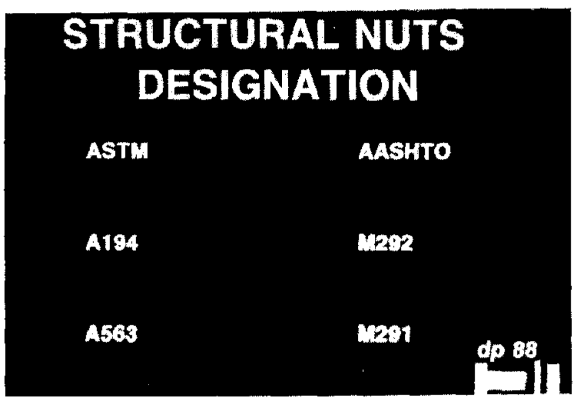
OTHER

- Specifications do not include electroplated fasteners for bridges.
- Only two types of coated fasteners, hot-dip galvanized and mechanically galvanized fasteners, are included in the specifications for bridge application.
- New coatings are being evaluated.



B - 6

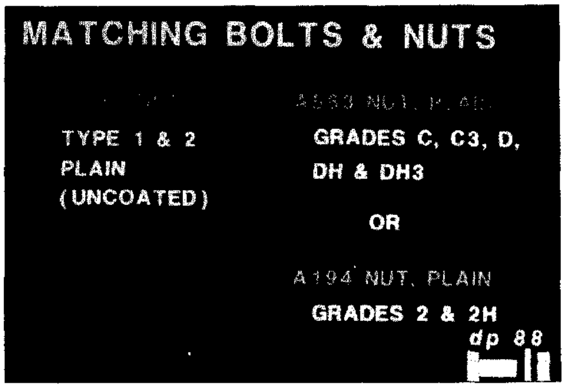
Structural Nuts and Nut Designation

A194 (M292) Nuts:

Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.

A653 (M291) Nuts:

Carbon and Alloy Steel Nuts.



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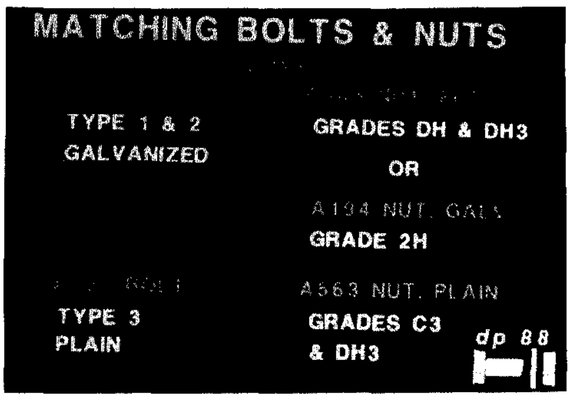

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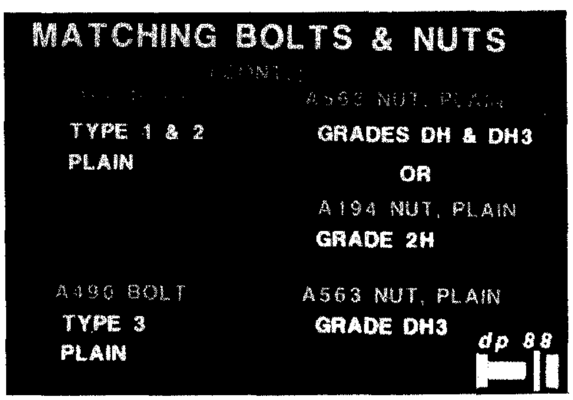

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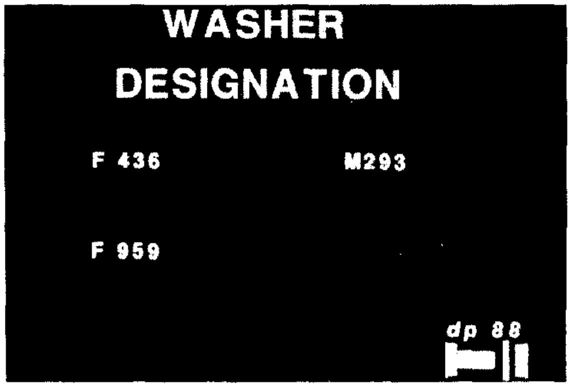
BOLT AND NUT SUITABILITY

A325 (M164) Bolt Assembly

- Type 3 bolts may be used in lieu of type 1 or type 2 uncoated bolts.
- Both nonheat-treated and heat-treated matching nuts are permitted with A325 (M164) bolts.
- Grades 2H, DH and DH3 are heat-treated grades of nuts.
- Only heat-treated nuts are galvanized.
- Overtapping and lubrication requirements for A194 (M292) grade 2H nuts are the same as those for A563 (M291) nuts.

A490 (M253) BOLT ASSEMBLY

- A490 (M253) bolts are not galvanized.
- Only heat-treated nuts are permitted for A490 (M253) bolts.



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WASHER DESIGNATION AND TYPES

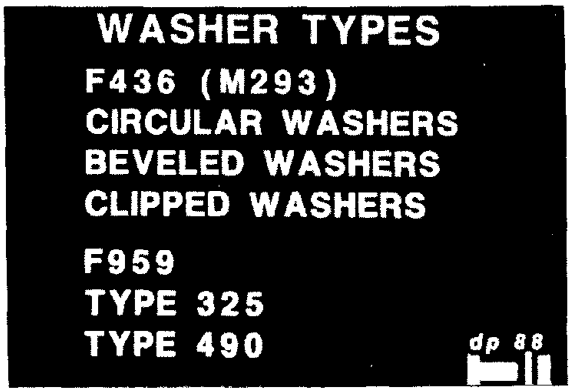
STEEL WASHERS

F436 (M293)

- Hardened Steel Washers
- Washers up to and including 1½ inch are through hardened.

F959

- Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners.



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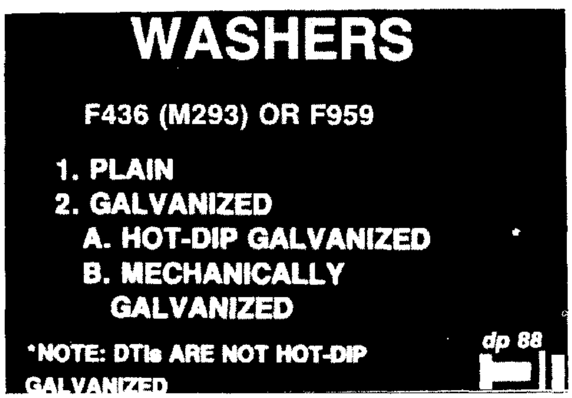
F436 (M293)

These washers are manufactured from plain carbon steel or steel having atmospheric corrosion resistance and weathering characteristics.

F959

Type 325 - DTI washer for use with A325 (M164) bolts.

Type 490 - DTI washer for use with A490 (M253) bolts.



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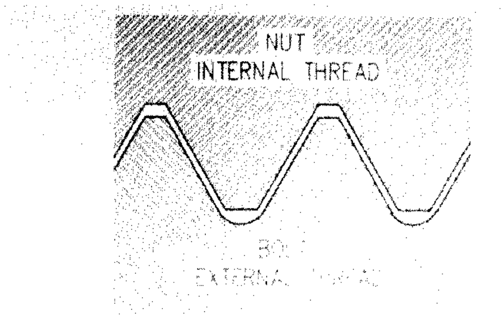
OTHER



EXTERNALLY THREADED FASTENERS

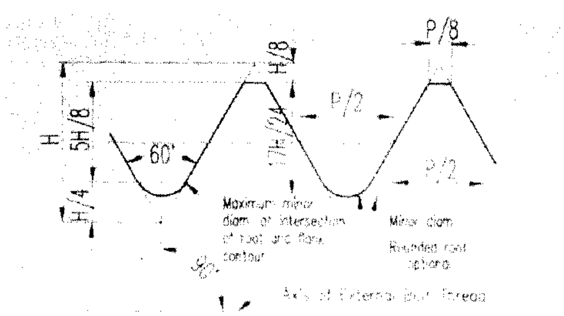
SCREW THREAD

Screw thread is defined as a ridge of uniform section in the form of a helix on the external or internal cylindrical surface.

NOTE: ASTM A325 (M164) and A490 (M253) bolts are manufactured to dimensions specified in ANSI B18.2.1 for Heavy Hex Structural Bolts.

THREAD PROFILE

- The crest, root and flanks make up the profile of the thread. The thread profile establishes the material boundary.
- The crests are located at the top, the roots are at the bottom, and the flanks join them.
- Incomplete threads occur at the runout where threads merge into unthreaded shank or tapped holes.

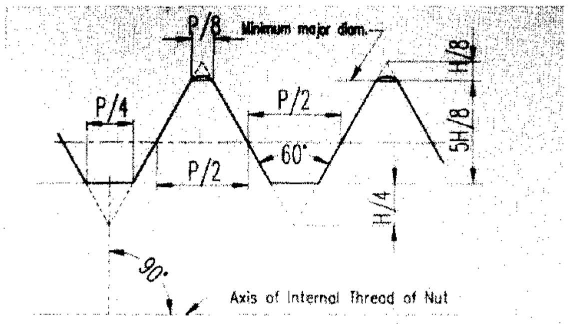


UNIFIED THREAD FORM

DIAMETER (Threaded Part)

For External Threads:

- The major diameter is the diameter at the thread crest.
- The minor diameter is the diameter at the thread root.



INTERNALLY THREADED FASTENERS

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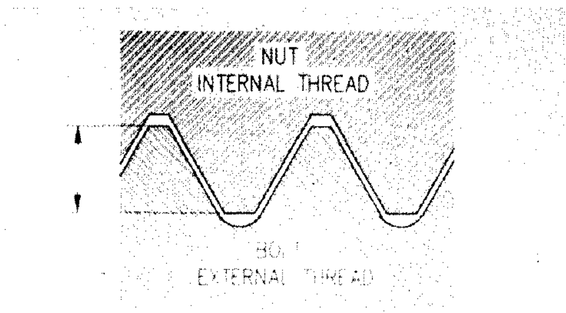
DIAMETER THREADED PART (Cont'd.)

For Internal Threads:

- The diameter at the root is the major diameter.
- The diameter at the crest is the minor diameter.



Depth of Thread Engagement (Interface)

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THREAD ENGAGEMENT

Half of the difference between minor diameter of the nut and the major diameter of the bolt thread determines the amount of overlap or the depth of thread engagement.

LENGTH OF THREAD ENGAGEMENT

In assembled fasteners, it is the axial distance through which the full threads of the external and internal fasteners are in contact.

PRELOAD

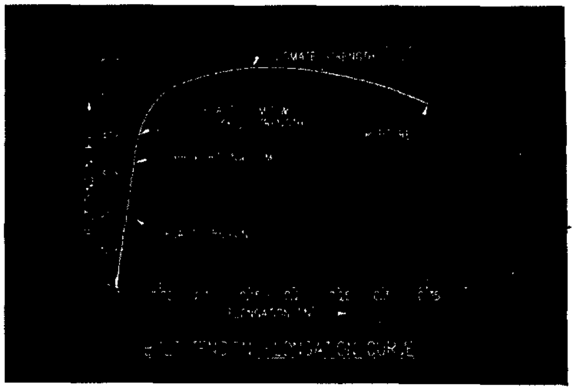
The initial clamping force and/or the tension in the fastener are usually called preload. (The tensile stress introduced to the fastener during the tightening process results in a tension force within the fastener, which in turn creates the clamping force on the joint.

PROOF LOAD (for bolts)

Proof load is defined as the minimum specified tensile force a bolt must withstand without resulting in any measurable permanent set.

STRESS AREA (standard threads)

Stress area is a cross-sectional area based on the mean value of the pitch and minor diameters of the threads.



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FROM LOAD vs. ELONGATION CURVES

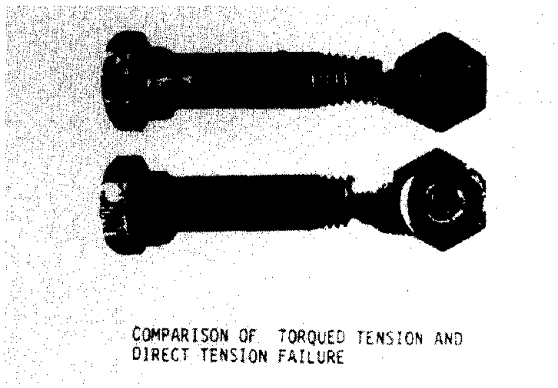
The elastic curve shows:

- Elastic Region: The initial straight line portion of the load vs. elongation curve.
- Proportional Limit: Upper end of the elastic region.
- Elastic Limit: Loading the fastener to this point will cause a particular amount of permanent deformation - usually chosen as .2 or 0.5 percent of the initial length. (Tension loads beyond this point will produce some permanent deformation).
- Yield Strength: Is the tension applied load at which a fastener experiences a specific amount of permanent deformation.
- Ductility: Is the ability of the material to deform before it fractures.

  The energy absorbed during the process of stretching is proportional to the area under the stress strain curve and is indicative of the ductility of the material.

  The common characteristics of ductility are determined by measuring change in length and reduction in area of a machined specimen. But this is not practical in the case of threaded fasteners.

  If the maximum hardness is not exceeded and if the wedge tensile test shows the required tensile strength--the ductility should be satisfactory.



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Ratio of:

$$\frac{\text{Specified Minimum Yield Strength}}{\text{Minimum Tensile Strength}}$$

is considered a reasonable indicator of ductility.

As this ratio goes down (↓) the ductility increases (↑).

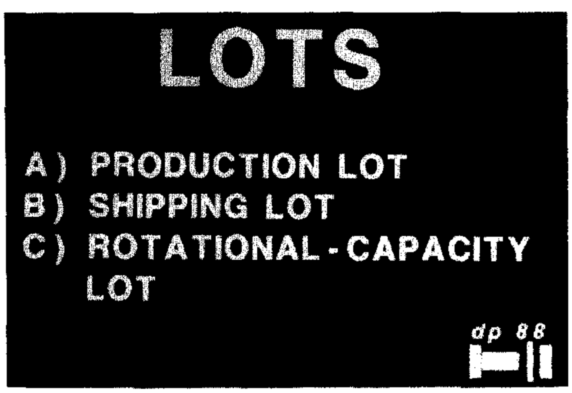
Note: Mechanical properties of bolts indicated on a load elongation curve depend on whether the bolt was subject to:

- direct tension

or

- torqued tension

Torque and friction induce three-dimensional stress effect in the bolt resulting in different behavior than the one represented by direct tension vs. elongation curve.



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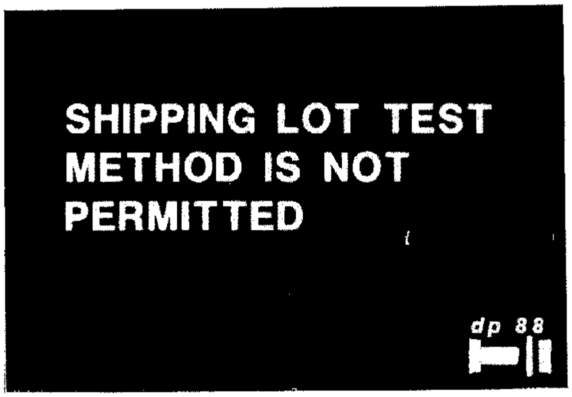
<u>LOTS</u>

<u>Production Lot</u>

- The production lot for any particular fastener (e.g., bolt, nut or washer) shall consist of fasteners processed essentially together through various manufacturing operations to shipping containers. A production lot will consist of fasteners of the same size and common characteristics (e.g., grade, finish, etc.), and produced from the same mill heat of steel.



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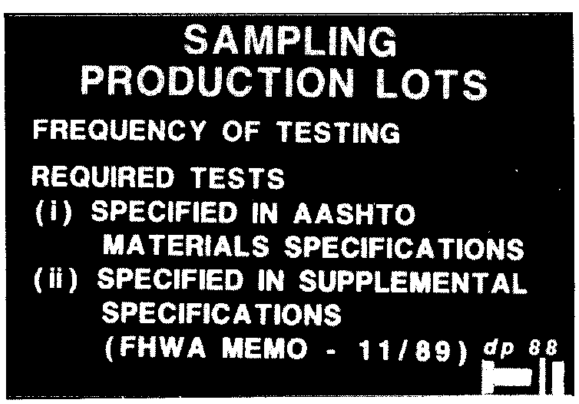
Shipping Lot

Shipping lot is defined as that quantity of fasteners of the same nominal size and the nominal length, as applicable, to fill the requirements of a single purchase order.

THE SHIPPING LOT TEST METHOD IS NOT PERMITTED BECAUSE THE FASTENER MAY OR MAY NOT HAVE BEEN MADE USING THE SAME PROCESS OR THE SAME MILL HEAT OF STEEL

Rotational-Capacity Lot

Rotational-capacity lot is defined as that quantity of fasteners from production lots of bolts, nuts and washers from which, when a certain specified number of fastener specimens are tested together as an assembly for rotational-capacity tests, they meet the test requirements.



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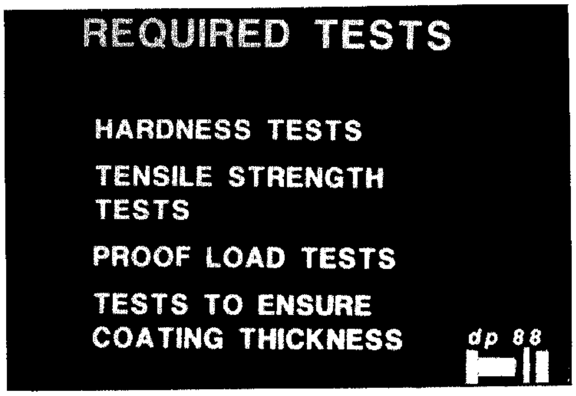
SAMPLING PRODUCTION LOTS

Prior to shipping fasteners production lots must be sampled by the manufacturer. Frequency of testing and test requirements vary depending on the type of fastener, i.e., whether it is a bolt, nut or washer. Refer to ASTM or AASHTO material specifications as appropriate. There are additional supplemental specifications for fasteners (FHWA Memorandum of November 1989) which will be discussed later.



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The following illustrates the requirements from the AASHTO Materials Specifications and FHWA Supplemental Specifications:

<u>EXAMPLE: M164 BOLTS</u>

Frequency of Testing

Number of Pieces in Production Lot	Number of Specimens
800 and less	1
801 to 8000	2
8001 to 35000	3
35001 to 150000	8
150001 and over	13

<u>CURRENTLY REQUIRED TESTS/ PRODUCTION LOTS</u>

As appropriate and depending on the type of fasteners (bolts, nuts or washers) the following tests are required:

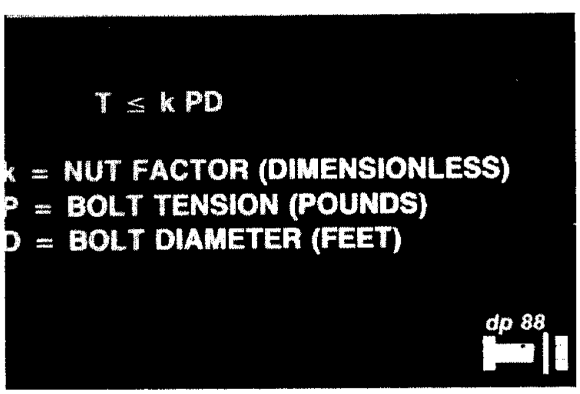
- Hardness tests
- Tensile strength tests
- Proof load tests (ASTM F606 Method 1)
- Tests to ensure coating thickness

<u>FREQUENCY OF TESTING FOR ROTATIONAL CAPACITY</u>

Rotational-capacity testing must be performed by the manufacturer or distributor, as appropriate, on two fastener assemblies per combination of production lots.

<u>NUT FACTOR</u>

Nut factor is the slope of the line representing torque-tension relationship.



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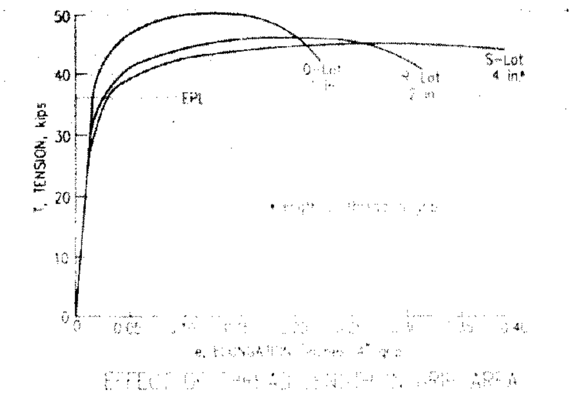

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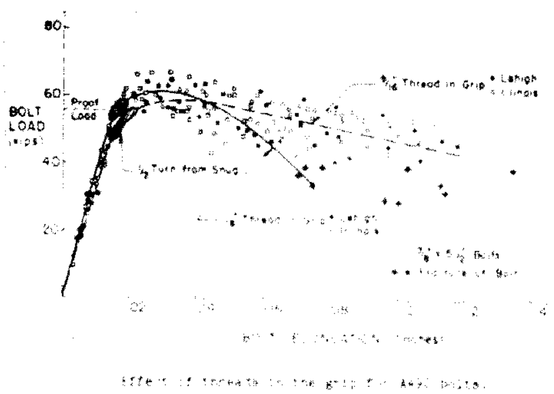

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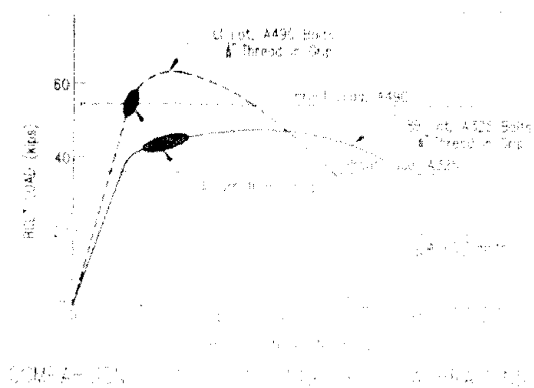

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DUCTILITY OF BOLT ASSEMBLY
VS.
NUMBER OF THREADS IN THE GRIP

Considering bolts of the same type

- The ductility increases (↑) as the number of threads are increased (↑) in the grip.
- The maximum strength reduces (↓) as the number of threads are increased (↑) in the grip.

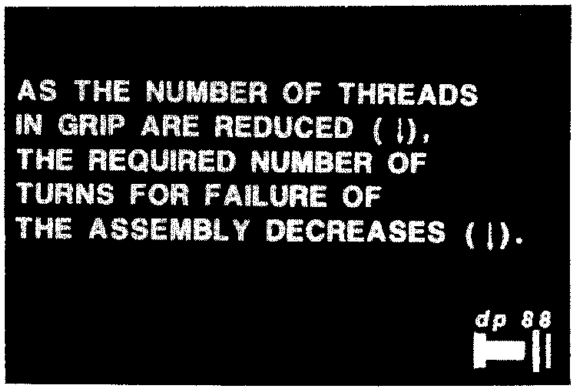
NOTE: A325 fasteners don't seem to be sensitive to the values of maximum tensile strength with respect to thread length in grip.

SENSITIVITY OF A490 (M253) BOLTS TO THREAD LENGTH IN GRIP

Lehigh University study shows that A490 (M253) bolts are relatively more sensitive to the number of threads in the grip, when compared with A325 (M164) bolts.

VARIATION IN MAXIMUM STRENGTH OF A490 (M253) BOLTS AND A325 (M164) BOLTS FOR THE SAME THREAD LENGTH IN THE GRIP

- With A490 (M253) bolts, the decrease in tension after the maximum tension is reached is much more rapid than the unloading experienced in a comparable A325 (M164) bolt assembly.
- A490 (M253) bolts have reduced ductility compared to a comparable size A325 (M164) bolt having the same length of thread in the grip.



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OBSERVATION

We saw that:

- As the number of threads in the grip are reduced, the assembly becomes less ductile.
- As the number of threads in the grip are reduced, the number of turns to failure are reduced.

Thus:

As ductility reduces (↓) required number of turns to failure reduce.

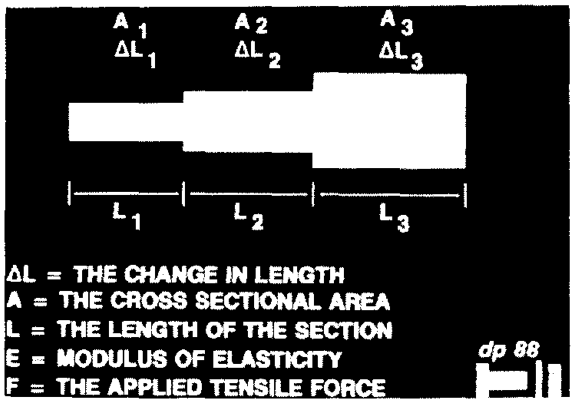
The standard heavy hexagonal structural bolts with short threaded lengths normally provide between 3/8" and 5/8" of thread within the grip. This would translate to about 2 turns to failure for A325 (M164) bolts.

SIGNIFICANCE OF NUT FACTOR

Variation in values of nut factor was noted because of wide variations in the thread interface conditions of the fasteners in the field.

Variation in nut factor can cause significant change in bolt tension for a given torque. The example illustrates the following:

- If the thread surface condition is changed from lubricated to clean condition, the force in the bolt would change from 53 kips to 33 kips for the same torque to 600 ft. pounds.
- Similarly, torque required to achieve the same bolt tension would depend on the thread surface condition.
- While bolts with different thread surface conditions require different values of torque, calibration test on fasteners of the same surface condition should provide a reliable installation torque.



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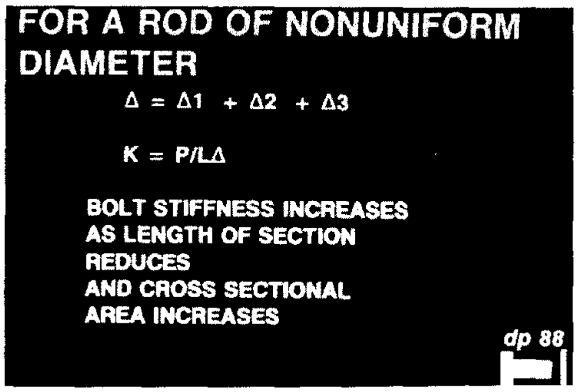
SHORT BOLTS/LONG BOLTS and BOLT STIFFNESS

In order to understand stress distribution within a bolt and to determine preload and clamping force, the stiffness of bolt should be determined -- i.e., the force required to deform the bolt by a unit length.



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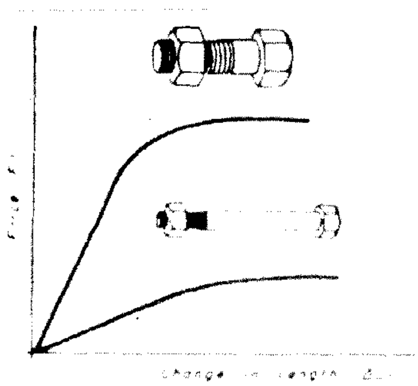
FOR A ROD OF NONUNIFORM DIAMETER

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} \quad Eq. (1)$$

$$\frac{1}{k} = \frac{L_1}{A_1 E} + \frac{L_2}{L_2 E} + \frac{L_3}{L_3 E} \quad Eq. (2)$$

Thus, the stiffness depends on the ratio of length and area of cross section of individual sections.



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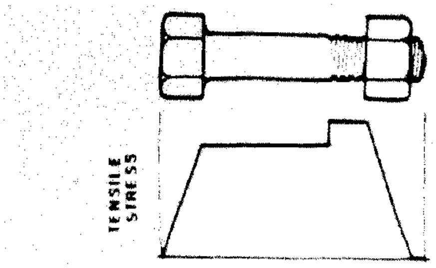
BEHAVIOR OF SHORT AND LONG BOLT



ASSUMED AND SIMPLIFIED VARIATION OF TENSILE STRESS

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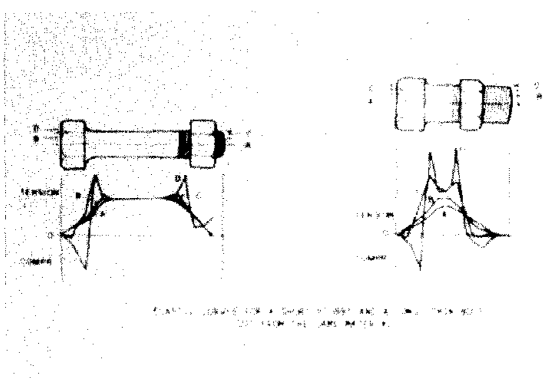
SIMPLIFIED STRESS DISTRIBUTION IN A BOLT SUBJECT TO TENSION

The stress distribution pattern in a bolt subject to tension suggests the following critical locations of high stress intensity:

- Fillet where bolt head joins shank.
- Thread run-out point where the thread meets the shank.
- The first thread to engage the nut.



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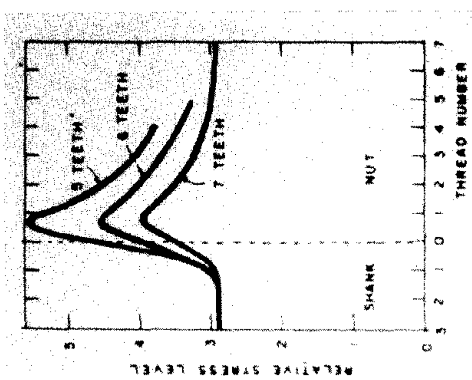
A MORE ACCURATE PLOT OF STRESS DISTRIBUTION IN A BOLT SUBJECT TO TENSION

Actual stress distribution along lines parallel to the axis of the bolt suggests that the stress concentration at the fillet and nut-bolt engagement point can be two to four times the average stress in the body of the long thin bolts (grip length/bolt dia. > 4:1) (Short bolts show no uniform stress variation in the body).



PEAK STRESSES IN NUT OR BOLT THREADS

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PEAK STRESSES DISTRIBUTION IN NUT/OR BOLT THREADS

- The first three threads generally carry most load.
- Peak values of stresses in nut or bolt threads are not reduced by adding more threads (e.g., using a longer nut).

APPENDIX C

November 1989

SUPPLEMENTAL CONTRACT SPECIFICATIONS FOR PROJECTS WITH AASHTO M164 (ASTM A325) HIGH-STRENGTH BOLTS

A. **Scope**

A1. All AASHTO M164 (ASTM A325) high-strength bolts, nuts and washers shall be furnished in accordance with the appropriate AASHTO Materials Specifications as amended and revised herein.

Additional requirements for field or shop installation of AASHTO M164 (ASTM A325) high-strength bolts are also included. These additional requirements supplement AASHTO Division II, Section 10.

B. **Specifications**

B1. All bolts shall meet the requirements of AASHTO M164 (ASTM A325) and these revisions.

B2. All nuts shall meet the requirements of AASHTO M292 (ASTM A194) as applicable or AASHTO M291 (ASTM A563) and these revisions.

B3. All washers shall meet the requirements of AASHTO M293 (ASTM F436) and these revisions.

C. **Manufacturing**

C1. Bolts

1. Hardness for bolt diameters 1/2 inch to 1 inch inclusive shall be as noted below:.

	Hardness Number			
Bolt Size, In.	Brinell		Rockwell C	
	Min.	Max.	Min.	Max.
1/2 to 1 inch	248	311	24	33

C2. Nuts

1. Nuts to be galvanized (hot dip or mechanically galvanized) shall be heat treated grade 2H, DH, or DH3.

2. Plain (ungalvanized) nuts shall be grades 2, C, D or C3 with a minimum Rockwell hardness of 89 HRB (or Brinell hardness 180 HB), or heat treated grades 2H, DH, or DH3. (The hardness requirements for grades 2, C, D and C3 exceed the current AASHTO/ASTM requirements.)

3. Nuts that are to be galvanized shall be tapped oversize the minimum amount required for proper assembly. The amount of overtap in the nut shall be such that the nut will assemble freely on the bolt in the coated condition and shall meet the mechanical requirements of AASHTO M291 (ASTM A563) and the rotational-capacity test herein (the overtapping requirements of AASHTO M291 [ASTM A563] paragraph 7.4 shall be considered maximum values instead of minimum, as currently shown).

4. Galvanized nuts shall be lubricated with a lubricant containing a dye of any color that contrasts with the color of the galvanizing..

C3. Marking - All bolts, nuts and washers shall be marked in accordance with the appropriate AASHTO/ASTM Specifications.

D. **Testing**

D1. Bolts

1. Proof load tests (ASTM F606 Method 1) are required. Minimum frequency of tests shall be as specified in AASHTO M164 (ASTM A325) paragraph 9.2.4.

2. Wedge tests on full size bolts (ASTM F606 paragraph 3.5) are required. If bolts are to be galvanized, tests shall be performed after galvanizing. Minimum frequency of tests shall be as specified in AASHTO M164 (ASTM A325) paragraph 9.2.4.

3. If galvanized bolts are supplied, the thickness of the zinc coating shall be measured. Measurements shall be taken on the wrench flats or top of bolt head.

D2. Nuts

1. Proof load tests (ASTM F606 paragraph 4.2) are required. Minimum frequency of tests shall be as specified in AASHTO M291 (ASTM A563) paragraph 9.3 or AASHTO M292 (ASTM A194) paragraph 7.1.2.1. If nuts are to be galvanized, tests shall be performed after galvanizing, overtapping and lubricating.

2. If galvanized nuts are supplied, the thickness of the zinc coating shall be measured. Measurements shall be taken on the wrench flats.

D3. Washers

1. If galvanized washers are supplied, hardness testing shall be performed after galvanizing. (Coating shall be removed prior to taking hardness measurements).

2. If galvanized washers are supplied, the thickness of the zinc coating shall be measured.

D4. Assemblies

1. Rotational-capacity tests are required and shall be performed on all black or galvanized (after galvanizing) bolt, nut and washer assemblies by the manufacturer or distributor prior to shipping. Washers are required as part of the test even though they may not be required as part of the installation procedure.

   The following shall apply:

   a. Except as modified herein, the rotational-capacity test shall be performed in accordance with the requirements of AASHTO M164 (ASTM A325).

   b. Each combination of bolt production lot, nut lot and washer lot shall be tested as an assembly. Where washers are not required by the installation procedures, they need not be included in the lot identification.

   c. A rotational-capacity lot number shall be assigned to each combination of lots tested.

   d. The minimum frequency of testing shall be two assemblies per rotational-capacity lot.

   e. The bolt, nut and washer assembly shall be assembled in a Skidmore-Wilhelm Calibrator or an acceptable equivalent device (note - this requirement supersedes the current AASHTO M164 (ASTM A325) requirement that the test be performed in a steel joint). For short bolts which are too short to be assembled in the Skidmore-Wilhelm Calibrator, See Section D4.1i.

   f. The minimum rotation, from a snug tight condition (10% of the specified proof load), shall be:

      240° (2/3 turn) for bolt lengths < 4 diameters
      360° (1 turn) for bolt lengths > 4 diameters and < 8 diameters
      480° (1 1/3 turn) for bolt lengths > 8 diameters

      (Note: that these values differ from the AASHTO M164 Table 8/ ASTM A325 Table 6 Specifications).

g. The tension reached at the above rotation shall be equal to or greater than 1.15 times the required installation tension. The installation tension and the tension for the turn test are shown below:

Diameter (In.)	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Req. Installation Tension (kips)	12	19	28	39	51	56	71	85	103
Turn Test Tension (kips)	14	22	32	45	59	64	82	98	118

h. After the required installation tension listed above has been exceeded, one reading of tension and torque shall be taken and recorded. The torque value shall conform to the following:

$$\text{Torque} \leq 0.25\ PD$$

Where

Torque = measured torque (foot-pounds)
P = measured bolt tension (pounds)
D = bolt diameter (feet).

i. Bolts that are too short to test in a Skidmore-Wilhelm Calibrator may be tested in a steel joint. The tension requirement of Section D4.1g need not apply. The maximum torque requirement of Section D4.1h shall be computed using a value of P equal to the turn test tension shown in the table in Section D4.1g.

D5. Reporting

1. The results of all tests (including zinc coating thickness) required herein and in the appropriate AASHTO specifications shall be recorded on the appropriate document.

2. Location where tests are performed and date of tests shall be reported on the appropriate document.

D6. Witnessing

1. The tests need not be witnessed by an inspection agency; however, the manufacturer or distributor that performs the tests shall certify that the results recorded are accurate.

E. Documentation

E1. Mill Test Report(s) (MTR)

1. MTR shall be furnished for all mill steel used in the manufacture of the bolts, nuts, or washers.

2. MTR shall indicate the place where the material was melted and manufactured.

E2. Manufacturer Certified Test Report(s) (MCTR)

1. The manufacturer of the bolts, nuts and washers shall furnish test reports (MCTR) for the item furnished.

2. Each MCTR shall show the relevant information required in accordance with Section D5.

3. The manufacturer performing the rotational-capacity test shall include on the MCTR:

   a. The lot number of each of the items tested.

   b. The rotational-capacity lot number as required in Section D4.1c.

   c. The results of the tests required in Section D4.

   d. The pertinent information required in Section D5.2.

   e. A statement that MCTR for the items are in conformance to this specification and the appropriate AASHTO specifications.

   f. The location where the bolt assembly components were manufactured.

E3. Distributor Certified Test Report(s)(DCTR)

1. The DCTR shall include MCTR above for the various bolt assembly components.

2. The rotational-capacity test may be performed by a distributor (in lieu of a manufacturer) and reported on the DCTR.

3. The DCTR shall show the results of the tests required in Section D4.

4. The DCTR shall also show the pertinent information required in Section D5.2.

5. The DCTR shall show the rotational-capacity lot number as required in Section D4.1c.

6. The DCTR shall certify that the MCTR are in conformance to this specification and the appropriate AASHTO specifications.

F. Shipping

F1. Bolts, nuts and washers (where required) from each rotational-capacity lot shall be shipped in the same container. If there is only one production lot number for each size of nut and washer, the nuts and washers may be shipped in separate containers. Each container shall be permanently marked with the rotational-capacity lot number such that identification will be possible at any stage prior to installation.

F2. The appropriate MTR, MCTR or DCTR shall be supplied to the contractor or owner as required by the Contract Documents.

G. Installation

The following requirements for installation apply in addition to the specifications in AASHTO Division II, Section 10 when high-strength bolts are installed in the field or shop.

G1. Bolts shall be installed in accordance with AASHTO Division II Article 10.17.4. During installation, regardless of the tightening method used, particular care should be exercised so that the snug tight condition as defined in Article 10.17.4 is achieved.

G2. The rotational-capacity test described in Section D4 above shall be performed on each rotational-capacity lot prior to the start of bolt installation. Hardened steel washers are required as part of the test although they may not be required in the actual installation procedures.

G3. A Skidmore-Wilhelm Calibrator or an acceptable equivalent tension measuring device shall be required at each job site during erection. Periodic testing (at least once each working day when the calibrated wrench method is used) shall be performed to assure compliance with the installation test procedures required in AASHTO Division II, Article 10.17.4.1 for Turn-of-Nut Tightening, Calibrated Wrench Tightening, Installation of Alternate Design Bolts and Direct Tension Indicator Tightening. Bolts that are too short for the Skidmore-Wilhelm Calibrator may be tested using direct tension indicators (DTIs). The DTIs must be calibrated in the Skidmore-Wilhelm Calibrator using longer bolts.

G4. Lubrication

1. Galvanized nuts shall be checked to verify that a visible lubricant is on the threads.

2. Black bolts shall be "oily" to the touch when delivered and installed.

3. Weathered or rusted bolts or nuts not satisfying the requirements of G2 or G3 above shall be cleaned and relubricated prior to installation. Recleaned or relubricated bolt, nut and washer assemblies shall be retested in accordance with G2 above prior to installation.

G5. Bolt, nut and washer (when required) combinations as installed shall be from the same rotational-capacity lot.

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Endorsed by
Manufacturers Standardization Society
of the Valve and Fittings Industry
Used in USNRC-RDT Standards

Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service[1]

This standard is issued under the fixed designation A 194/A 194M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification[2] covers a variety of carbon, alloy, and martensitic stainless steel nuts in the size range ¼ through 4 in. [6.4 through 101.6 mm] nominal. It also covers austenitic stainless steel nuts in the size range ¼ in. [6.4 mm] nominal and above. These nuts are intended for high-pressure or high-temperature service or both. Grade substitutions without the purchaser's permission are not allowed.

1.2 Bars from which the nuts are made shall be hot-wrought. The material may be further processed by centerless grinding or by cold drawing. Austenitic stainless steel may be solution annealed or annealed and strain-hardened.

1.3 Supplementary requirements (S1 through S6) of an optional nature are provided. These shall apply only when specified in the inquiry, contract, and order.

1.4 This specification is expressed in both inch-pound units and in SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in noncomformance with the specification.

NOTE—Grade 2M has been replaced with Grade 2HM. During a transition period both grade markings are acceptable.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished[3]

A 276 Specification for Stainless and Heat-Resisting Steel Bars and Shapes[3]

A 320/A 320M Specification for Alloy-Steel Bolting Materials for Low-Temperature Service[4]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[5]

A 484/A 484M Specification for General Requirements for Stainless and Heat-Resisting Bars, Billets, and Forgings[3]

A 788 Specification for Steel Forgings, General Requirements[3]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[6]

E 381 Method of Macroetch Testing, Inspection, and Rating Steel Products, Comprising Bars, Billets, Blooms, and Forgings[7]

2.2 *American National Standards:*[8]

B1.1 Unified Screw Threads

B1.2 Gages and Gaging for Unified Screw Threads

B18.2.2 Square and Hex Nuts

3. Terminology

3.1 *Descriptions of Terms Specific to This Standard:*

3.1.1 *Lot:*

3.1.1.1 Unless otherwise specified (see 3.1.1.2), a lot is the quantity of nuts of a single nominal size and grade produced by the same manufacturing process.

3.1.1.2 When Supplementary Requirement S6 is invoked on the purchase order, the following definitions of a lot shall apply:

For Grade 8 Nuts—The quantity of all the nuts of a single nominal diameter and grade made from the same heat of steel and made by the same manufacturing process.

For All Other Grade Nuts (see 7.2 and 7.1.2.1)—All the nuts of a single nominal diameter and grade made from the same heat number and heat treated in the same batch if batch-type heat treating equipment is used or heat treated in the same continuous run of not more than 8 h under the same conditions if continuous-type heat treating equipment is used.

3.1.2 *Type:*

3.1.2.1 *For Grade 8 Nuts*—Variations within the grade

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.22 on Valves and Fittings.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-194 in Section II of that code.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

[4] *Annual Book of ASTM Standards*, Vol 01.01.

[5] *Annual Book of ASTM Standards*, Vols 01.01 and 01.04.

[6] *Annual Book of ASTM Standards*, Vols 02.03 and 03.01.

[7] *Annual Book of ASTM Standards*, Vol 03.01.

[8] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

designated by a letter and as differentiated by chemistry and by manufacturing process.

3.1.2.2 *For Grade 6 Nuts*—Variations within the grade designated by the letter F as differentiated by chemical additions made for machineability.

3.1.3 *Series*—The dimensional relationship and geometry of the nuts as described in ANSI B18.2.2.

4. Ordering Information

4.1 The inquiry and order for material under this specification shall include the following as required to describe the material adequately:

4.1.1 ASTM Specification A 194/A 194M (current issue), grade as selected from Table 1, and the text of this specification,

4.1.2 Quantity, number of pieces,

4.1.3 Dimensions (see Section 9),

4.1.4 Options in accordance with 6.1, 7.2.2.1, 9.1, 9.2, 10.3, 11, 12, and 13, and

4.1.5 Supplementary Requirements, if any.

5. Manufacture (Process)

5.1 The steel shall be produced by any one of the following processes: open-hearth, basic-oxygen, electric-furnace, or vacuum-induction melting (VIM). The primary melting method may incorporate separate degassing or refining. The molten steel may be vacuum-treated prior to or during pouring of the ingot or strand casting. The basic-oxygen process shall be limited to steels containing not over 6 % chromium.

5.1.1 *Quality*—The producer quality control procedures shall provide sufficient testing of Carbon and Alloy Steels in accordance with Method E 381 as stipulated in Sections 5, 7 and 8 or another suitable method as agreed upon between the purchaser and the producer to ensure the internal quality of the product. A bar lot consisting of one heat or 10 000 lbs, whichever is smaller, shall be represented by a minimum of one macroetch. Visual examination of transverse sections shall show no imperfections worse than the macrographs of Method E 381 S4-R4-C4 or equivalent as agreed upon. Distinct zones of solidification shall not be present.

5.2 Stainless steels for all types of Grade 6 and 8 nuts shall be made by one of the following processes:

5.2.1 Electric-furnace (with separate degassing and refining optional),

5.2.2 Vacuum induction furnace, or

5.2.3 Either of the above followed by electroslag remelting, or consumable-arc remelting.

5.3 The steel producer shall exercise adequate control to eliminate excessive unhomogeneity, nonmetallics, pipe, porosity, and other defects.

5.4 Grades 1 and 2 nuts shall be hot or cold forged, or shall be machined from hot-forged, hot-rolled, or cold-drawn bars.

5.4.1 All Grade 1 and 2 nuts made by cold forging or by machining from cold-drawn bars shall be stress-relief annealed at a temperature of at least 1000°F [538°C].

5.4.2 Grade 1 and 2 nuts made by hot forging or by machining from hot-forged or hot-rolled bars need not be given any stress relief annealing treatment.

5.5 Grades 2HM, 2H, 3, 4, 6, 6F, 7, and 7M nuts shall be hot or cold-forged or shall be machined from hot-forged, hot-rolled, or cold-drawn bars and shall be heat treated to meet the required mechanical properties. However, nuts machined from heat-treated bars need not be reheat treated. See Supplementary Requirement S4 for nuts to be used in low-temperature applications (Specification A 320/A 320M). These grades of nuts shall be reheated above the critical range of the steel, quenched in a suitable medium, and then tempered at a temperature not less than the following:

Grade and Type	Minimum Tempering Temperature, °F [°C]
2H	850 [455]
2HM	1150 [620]
3	1050 [565]
4	1100 [595]
6 and 6F	1100 [595]
7 and 7M	1100 [595]

5.5.1 Grade 6 and 6F nuts shall be tempered for a minimum of 1 h at the temperature.

5.6 Grades 8, 8C, 8M, 8T, 8F, 8P, 8N, 8MN, 8R, 8S, 8LN, and 8MLN nuts shall be hot or cold forged, or shall be machined from hot-forged, hot-rolled or cold-drawn bars.

5.7 Grades 8A, 8CA, 8MA, 8TA, 8FA, 8PA, 8NA, 8MNA, 8RA, 8SA, 8LNA, and 8MLNA nuts shall be hot or cold-forged or shall be machined from hot-forged, hot-rolled, or cold-drawn bars and the nuts shall subsequently be carbide-solution treated by heating them for a sufficient time at a temperature to dissolve chromium carbides followed by cooling at a rate sufficient to prevent reprecipitation of the carbides.

6. Chemical Composition

6.1 An analysis of each heat of steel used for nuts shall be made by the manufacturer during the pouring of the steel. For strand cast materials, the requirements of 8.2 and 8.3 of Specification A 788 shall be met. Should the purchaser deem it necessary to have the transition zone of two heats sequentially cast discarded, the purchaser shall invoke Supplementary Requirement S3 of Specification A 788.

6.2 The heat analysis of the nut materials shall conform to the chemical composition requirements for the grade ordered as specified in Table 1. Nuts that are normally furnished from stock are not identified by heat number, and thus heat analysis cannot normally be reported to the purchaser. (See Supplementary Requirement S2.) Supplementary Requirement S6 is provided for use when heat analysis control is required.

6.3 Steels with added lead shall not be used.

6.4 Product analyses may be made by the purchaser from a sample nut selected by the purchaser or the purchaser's representative from each item in the shipment which shall meet the product analysis requirements for the grade ordered in Table 1. Product analysis tolerances are found in Tables 5 and 6 of Specification A 29/A 29M, and Table 1 of Specification A 484/A 484M.

6.5 A starting material that specifically requires the addition of any element beyond those listed in Table 1 is not permitted. This does not preclude the use of deoxidizers.

7. Mechanical Requirements

7.1 *Hardness Test:*

TABLE 1 Chemical Requirements [A,B]

Grade Symbol	Material	Carbon, %	Manganese, %	Phosphorus, %	Sulfur,[C] %	Silicon, %	Chromium, %	Nickel, %	Molybdenum, %	Titanium, %	Columbium and Tantalum, %	Selenium, %	Other Elements, %
1	carbon	0.15 min	1.00 max	...	...	0.40 max	...	...	...	...	...	...	...
2, 2HM, and 2H	carbon	0.40 min	1.00 max	0.040 max	0.050 max	0.40 max	...	...	...	...	...	...	...
4	carbon, molybdenum	0.40–0.50	0.70–0.90	0.035 max	0.040 max	0.15–0.35	...	...	0.20–0.30	...	...	...	...
3	AISI 501	0.10 min	1.00 max	0.040 max	0.030 max	1.00 max	4.00–6.00	...	0.40–0.65	...	...	...	...
6	AISI 410	0.15 max	1.00 max	0.040 max	0.030 max	1.00 max	11.50–13.50	...	...	...	...	...	...
6F	AISI 416 with sulfur	0.15 max	1.25 max	0.060 max	0.15 min	1.00 max	12.00–14.00	...	...	...	...	...	
6F	AISI 416 with selenium	0.15 max	1.25 max	0.060 max	0.060 max	1.00 max	12.00–14.00	...	...	...	...	0.15 min	...
7, 7M	AISI 4140/4142/4145, 4140H, 4142H, 4145H	0.37–0.49	0.65–1.10	0.04 max	0.04 max	0.15–0.35	0.75–1.20	...	0.15–0.25	...	...	...	...
8, 8A	AISI 304	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–10.50	...	...	...	...	...
8C, 8CA	AISI 347	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	9.00–13.00	...	...	10× carbon content, min	...	...
8M, 8MA	AISI 316	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–14.00	2.00–3.00	...	...	...	...
8T, 8TA	AISI 321	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	9.00–12.00	...	5× carbon content, min	...	...	...
8F, 8FA	AISI 303 with sulfur	0.15 max	2.00 max	0.20 max	0.15 min	1.00 max	17.00–19.00	8.00–10.00	...	...	...	...	
8F, 8FA	AISI 303 with selenium	0.15 max	2.00 max	0.20 max	0.06 max	1.00 max	17.00–19.00	8.00–10.00	...	...	...	0.15 min	...
8P, 8PA	AISI 305 with restricted carbon	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	10.50–13.00	...	...	...	...	...
8N, 8NA	AISI 304N	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–10.50	...	...	...	...	Nitrogen, 0.10–0.16
8LN, 8LNA	AISI 304N with restricted carbon	0.030 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–10.50	...	...	...	...	Nitrogen, 0.10–0.16
8MN, 8MNA	AISI 316N	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–14.00	2.00–3.00	...	...	...	Nitrogen, 0.10–0.16
8MLN, 8MLNA	AISI 316N with restricted carbon	0.030 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–14.00	2.00–3.00	...	...	...	Nitrogen, 0.10–0.16
8R, 8RA [D]	XM19	0.06 max	4.00–6.00	0.040 max	0.030 max	1.00 max	20.50–23.50	11.50–13.50	1.50–3.00	...	0.10–0.30	...	Nitrogen, 0.20–0.40 Vanadium, 0.10–0.30
8S, 8SA	[E]	0.10 max	7.00–9.00	0.040 max	0.040 max	3.50–4.50	16.00–18.00	8.00–9.00	...	...	...	...	Nitrogen, 0.08–0.18

[A] The intentional addition of Bi, Se, Te, and Pb is not permitted except for Grades 6F, 8F, and 8FA, in which Se is specified and required.

[B] Product Analysis—Individual determinations sometimes vary from the specified limits on ranges as shown in the table. The several determinations of any individual element in a heat may not vary both above or below the specified range. Product analysis tolerances may be found in Tables 5 and 6 of Specification A 29/A 29M, and Table 1 of Specification A 484/A 484M.

[C] Because of the degree to which sulfur segregates, product analysis for sulfur over 0.060 % max is not technologically appropriate.

[D] As described in Specification A 276.

[E] Similar to grade S21800 of Specification A 276, except phosphorus is restricted to 0.040 % max.

TABLE 2 Hardness Requirements

Grade and Type	Completed Nuts			Sample Nut after Treatment as in 7.1.5.2	
	Brinell Hardness	Rockwell Hardness		Brinell Hardness, min	Rockwell Hardness B Scale, min
		C Scale	B Scale		
1	121 min	...	70 min	121	70
2	159 to 352	...	84 min	159	84
2H	248 to 352	24 to 38	...	179	89
To 1½ in. [38.1 mm], incl	248 to 352	24 to 38	...	179	89
Over 1½ in. [38.1 mm]	212 to 352	38 max	95 min	147	79
2HM and 7M	159 to 237	22 max	...	159	84
3, 4, and 7	248 to 352	24 to 38	...	201	94
6 and 6F	228 to 271	20 to 28	...	...	...
8, 8C, 8M, 8T, 8F, 8P, 8N,	126 to 300	...	60 to 105	...	...
8MN, 8LN, and 8MLN	126 to 300	...	60 to 105	...	...
8A, 8CA, 8MA, 8TA,	126 to 192	...	60 to 90	...	...
8FA, 8PA, 8NA, 8MNA,	126 to 192	...	60 to 90	...	...
8LNA, and 8MLNA	126 to 192	...	60 to 90	...	...
8R, 8RA, 8S, and 8SA	183 to 271	B 88 to C 25	...	...	...

7.1.1 *Requirements:*

7.1.1.1 All nuts shall be capable of meeting the hardness requirements specified in Table 2.

7.1.1.2 Sample nuts of Grades 1, 2, 2H, 2HM, 3, 4, 7, and 7M which have been given the treatment described in 7.1.5.2 shall meet the minimum hardness specified in Table 2.

7.1.2 *Number of Tests* (Grades 1, 2, 2H, 3, 4, and 7 and all types of Grade 6):

7.1.2.1 Tests on the number of sample nuts in accordance with the following table shall be performed in accordance with 7.1.5.1 by the manufacturer following all production heat treatments:

Lot Size	Samples
Up to 800	1
801 to 8000	2
8001 to 22 000	3
Over 22 000	5

7.1.2.2 In addition, a hardness test shall be performed by the manufacturer in accordance with 7.1.5.2 on one sample nut selected from each nominal diameter and series from each grade and heat number following completion of all production heat treatments.

7.1.3 *Number of Tests, Grades 2HM and 7M:*

7.1.3.1 The maximum hardness of Grade 2HM and 7M shall be 235 HB or 99 HRB (conversion in accordance with Table 3B of Test Methods and Definitions A 370). Conformance to the maximum hardness shall be insured by testing the hardness of each nut by Brinell or Rockwell B methods as described in the sections on Brinell Test, Portable Hardness Test, and Rockwell Test of Test Methods and Definitions A 370. Surface preparation for hardness testing shall be in accordance with Test Methods E 18. Product which has been 100 % tested and found acceptable shall have a line under the "M."

7.1.3.2 In addition, 7.1.2.2 shall be met.

7.1.4 *Number of Tests, All Types of Grade 8*—Tests on the number of sample nuts in accordance with 7.1.2.1 shall be performed in accordance with 7.1.5.1 by the manufacturer.

7.1.5 *Test Methods:*

7.1.5.1 *Test 1*—The manufacturer shall perform the hardness tests in accordance with Supplement III, Paragraph S14.2 of Test Methods and Definitions A 370.

7.1.5.2 *Test 2*—The manufacturer shall perform hardness tests in accordance with 7.1.5.1 to sample nuts after the following test heat treatment. After completion of all production heat treatments heat the specimen nuts to the temperatures indicated below for 24 h, then slow cool. Test at room temperature.

Grade	Temperature, °F [°C]
1	850 [455]
2, 2H, 2HM	1000 [540]
3, 4, 7, 7M	1100 [590]

7.1.5.3 *Special Requirement, Grades 2HM and 7M*—Preparation of Grades 2HM and 7M nuts for hardness test and the hardness test itself shall be performed with consideration to (*1*) protect legibility of markings; (*2*) minimize exterior dimensional changes; and (*3*) maintain thread fit.

7.2 *Proof Load Test:*

7.2.1 *Requirements*—All nuts shall be capable of withstanding the proof loads specified in Table 3. However, nuts manufactured to dimensions and configurations other than those covered by ANSI B1.1 and B18.2.2 are not subject to the proof load test.

7.2.2 *Number of Tests:*

7.2.2.1 Tests on the number of sample nuts in accordance with 7.1.2.1 shall be performed by the manufacturer following all production heat treatments and with the following exceptions: nuts which would require a proof load in excess of 120 000 lbf [530 kN] may be furnished on the basis of minimum hardness requirements, unless proof load testing is specified in the inquiry and purchase order. Proof load testing of nuts requiring a proof load of over 120 000 lbf [530 kN] is covered in Supplementary Requirement S5.

7.2.3 *Test Method*—The test shall be in accordance with Supplement III, Paragraph S14.1, of Test Methods and Definitions A 370.

7.3 *Cone Proof Load Test:*

7.3.1 *Requirements*—This test shall be performed only when visible surface discontinuities become a matter of issue between the manufacturer and the purchaser. The requirements specified in Table 4 shall be met for the size range ¼ to 1½ in. [6.4 to 38.1 mm]. Nuts not in this size range and all types of Grade 8 nuts are not subject to this test. Also, nuts manufactured to dimensions and configurations other

TABLE 3 Proof Load Using Threaded Mandrel

NOTE—Proof loads are not design loads.

Nominal Size, in. [mm]	Threads per Inch [25.4 mm]	Stress Area, in.², [mm²]	Proof Load, lbf [kN]^A Grade 1		Grades 2, 2HM, 6 6F, 7M		Grades 2H, 3, 4, 7	
			Heavy Hex^B	Hex^C	Heavy Hex^D	Hex^E	Heavy Hex^F	Hex^G
1/4 [6.4]	20	0.0316 [20.4]	4 130 [18.4]	3 820 [17.0]	4 770 [21.2]	4 300 [19.1]	5 570 [24.8]	4 770 [21.2]
5/16 [7.9]	18	0.0524 [33.8]	6 810 [30.3]	6 290 [28.0]	7 860 [35.0]	7 070 [31.4]	9 170 [40.8]	7 860 [35.0]
3/8 [9.5]	16	0.0774 [49.9]	10 080 [44.8]	9 300 [41.4]	11 620 [51.7]	10 460 [46.5]	13 560 [60.3]	11 620 [51.7]
7/16 [11.1]	14	0.1063 [68.6]	13 820 [61.5]	12 760 [56.8]	15 940 [70.9]	14 350 [63.8]	18 600 [82.7]	15 940 [70.9]
1/2 [12.7]	13	0.1419 [91.5]	18 450 [82.1]	17 030 [75.8]	21 280 [94.6]	19 160 [85.2]	24 830 [110]	21 280 [94.6]
9/16 [14.2]	12	0.182 [117]	23 660 [105]	21 840 [97.1]	27 300 [121]	24 570 [109]	31 850 [142]	27 300 [121]
5/8 [15.9]	11	0.226 [146]	29 380 [131]	27 120 [121]	33 900 [151]	30 510 [136]	39 550 [176]	33 900 [151]
3/4 [19]	10	0.334 [215]	43 420 [193]	40 080 [178]	50 100 [223]	45 090 [200]	58 450 [260]	50 100 [223]
7/8 [22.2]	9	0.462 [298]	60 060 [267]	55 440 [247]	69 300 [308]	62 370 [277]	80 850 [360]	69 300 [308]
1 [25.4]	8	0.606 [391]	78 780 [350]	72 720 [323]	90 900 [404]	81 810 [364]	106 000 [472]	90 900 [404]
1 1/8 [28.6]	8	0.790 [510]	102 700 [457]	94 800 [422]	118 500 [527]	106 700 [475]	138 200 [615]	118 500 [527]
1 1/4 [31.8]	8	1.000 [645]	130 000 [578]	120 000 [534]	150 000 [667]	135 000 [600]	175 000 [778]	150 000 [667]
1 3/8 [34.9]	8	1.233 [795]	160 200 [713]	148 000 [658]	185 000 [823]	166 500 [741]	215 800 [960]	185 000 [823]
1 1/2 [38.1]	8	1.492 [962]	194 000 [863]	170 040 [756]	223 800 [996]	201 400 [896]	261 100 [1161]	223 800 [996]
			All Types of Grade 8		Grade 8M (Strain-Hardened)		All Other Types of Grade 8 (Strain-Hardened)	
			Heavy Hex^H	Hex^I	Heavy Hex^J	Hex^K	Heavy Hex^L	Hex^J
1/4 [6.4]	20	0.0316 [20.4]	2 540 [11.3]	2 380 [10.6]	3 480 [15.5]	3 160 [14.0]	3 950 [17.6]	3 480 [15.5]
5/16 [7.9]	18	0.0524 [33.8]	4 190 [18.6]	3 930 [17.5]	5 760 [25.6]	5 240 [23.3]	6 550 [29.1]	5 760 [25.6]
3/8 [9.5]	16	0.0774 [49.9]	6 200 [27.6]	5 810 [25.8]	8 510 [37.8]	7 740 [34.4]	9 675 [43.0]	8 510 [37.8]
7/16 [11.1]	14	0.1063 [68.6]	8 500 [37.8]	7 970 [35.4]	11 690 [52.0]	10 630 [47.3]	13 290 [59.1]	11 690 [52.0]
1/2 [12.7]	13	0.1419 [91.5]	11 350 [50.5]	10 640 [49.8]	15 610 [69.4]	14 190 [63.1]	17 740 [78.9]	15 610 [69.4]
9/16 [14.2]	12	0.182 [117]	14 560 [64.8]	13 650 [60.7]	20 020 [89.0]	18 200 [80.9]	22 750 [101]	20 020 [89.0]
5/8 [15.9]	11	0.226 [146]	18 080 [80.4]	16 950 [75.4]	24 860 [110]	22 600 [100]	28 250 [126]	24 860 [110]
3/4 [19]	10	0.334 [215]	26 720 [119]	25 050 [111]	36 740 [163]	33 400 [148]	41 750 [186]	36 740 [163]
7/8 [22.2]	9	0.462 [298]	36 960 [164]	34 650 [154]	46 200 [206]	41 580 [185]	53 130 [236]	46 200 [206]
1 [25.4]	8	0.606 [391]	48 480 [216]	45 450 [202]	60 600 [270]	54 540 [243]	69 690 [310]	60 600 [270]
1 1/8 [28.6]	8	0.790 [510]	63 200 [281]	59 250 [264]	75 050 [334]	67 150 [299]	82 950 [369]	75 050 [334]
1 1/4 [31.8]	8	1.000 [645]	80 000 [356]	75 000 [334]	95 000 [422]	85 000 [378]	105 000 [467]	95 000 [422]
1 3/8 [34.9]	8	1.233 [795]	98 640 [439]	92 450 [411]	110 970 [494]	98 640 [439]	123 300 [548]	110 970 [494]
1 1/2 [38.1]	8	1.492 [962]	119 360 [531]	111 900 [498]	134 280 [597]	119 360 [531]	149 200 [664]	134 280 [597]

^A See limit for proof load test in 7.2.2.1. The proof load for jam nuts shall be 46 % of the tabulated load.
^B Based on proof stress of 130 000 psi [895 MPa].
^C Based on proof stress of 120 000 psi [825 MPa].
^D Based on proof stress of 150 000 psi [1035 MPa].
^E Based on proof stress of 135 000 psi [930 MPa].
^F Based on proof stress of 175 000 psi [1205 MPa].
^G Based on proof stress of 150 000 psi [1035 MPa].
^H Based on proof stress of 80 000 psi [550 MPa].
^I Based on proof stress of 75 000 psi [515 MPa].
^J Based on proof stress of 110 000 psi [760 MPa] up to 3/4 in. [19 mm]; 100 000 psi [690 MPa] 7/8 to 1 in. [22.2 to 25.4 mm]; 95 000 psi [655 MPa] 1 1/8 to 1 1/4 in. [28.6 to 31.8 mm]; 90 000 psi [620 MPa] 1 3/8 to 1 1/2 in. [34.9 to 38.1 mm].
^K Based on proof stress of 100 000 psi [690 MPa] up to 3/4 in. [19 mm]; 90 000 psi [620 MPa] 7/8 to 1 in. [22.2 to 25.4 mm]; 85 000 psi [585 MPa] 1 1/8 to 1 1/4 in. [28.6 to 31.8 mm]; 80 000 psi [550 MPa] 1 3/8 to 1 1/2 in. [34.9 to 38.1 mm].
^L Based on proof stress of 125 000 psi [860 MPa] up to 3/4 in. [19 mm]; 115 000 psi [795 MPa] 7/8 to 1 in. [22.2 to 25.4 mm]; 105 000 psi [725 MPa] 1 1/8 to 1 1/4 in. [28.6 to 31.8 mm]; 100 000 psi [690 MPa] 1 3/8 to 1 1/2 in. [34.9 to 38.1 mm].

than those covered by ANSI B1.1 and B18.2.2 are not subject to the cone proof load test.

7.3.2 *Number of Tests*—Sample nuts in accordance with 7.1.2.1 shall be tested by the manufacturer.

7.3.3 *Test Method*—The test shall consist of assembling a hardened cone (see Fig. 1) and the nut to be tested on a hardened steel mandrel, and applying the proof load specified in Table 4. The mandrel shall conform to the requirements of Supplement III, Paragraph S14.1 of Test Methods and Definitions A 370 except that the threads shall be in accordance with ANSI B1.1 of the appropriate thread series, Class 3A fit. The hardened cone shall be as described in Fig. 2. The lot shall be considered acceptable if the sample nut withstands application of the proof load without failure.

8. Retests

8.1 Provisions for retests by the purchaser and his representative are specified in Supplementary Requirement S3.

9. Dimensions

9.1 Nuts shall be hexagonal in shape, and in accordance with the dimensions for the hex or heavy hex series, as required, by ANSI B18.2.2. Unless otherwise specified, the American National Standard Heavy Hex Series shall be used and nuts shall be either double chamfered or have a machined or forged washer face, at the option of the manufacturer, and, conform to the angularity requirements of ANSI B18.2.2.

9.2 Unless otherwise specified, threads shall be in accord-

TABLE 4 Proof Load Using 120° Hardened Steel Cone[A]

Nominal Size, in. [mm]	Threads per Inch [25.4 mm]	Stress Area, in.^{2}, [mm^2]	Proof Load, lbf [kN]					
			Grade 1		Grades 2, 2HM, 6 6F, 7M		Grades 2H, 3, 4, 7	
			Heavy Hex[B]	Hex[C]	Heavy Hex[D]	Hex[E]	Heavy Hex[F]	Hex[D]
1/4 [6.4]	20	0.0318 [20.5]	3 800 [16.9]	3 550 [15.8]	4 400 [19.6]	4 000 [17.8]	5 150 [22.9]	4 400 [19.6]
5/16 [7.9]	18	0.0524 [33.8]	6 150 [27.4]	5 700 [25.4]	7 100 [31.6]	6 400 [28.5]	8 300 [36.9]	7 100 [31.6]
3/8 [9.5]	16	0.0774 [49.9]	8 950 [39.8]	8 250 [36.7]	10 300 [45.8]	9 300 [41.4]	12 000 [53.4]	10 300 [45.8]
7/16 [11.1]	14	0.1063 [68.6]	12 000 [53.4]	11 100 [49.4]	13 850 [61.6]	12 450 [55.4]	16 150 [71.8]	13 850 [61.6]
1/2 [12.7]	13	0.1419 [91.5]	15 700 [69.8]	14 500 [64.5]	18 100 [80.5]	16 300 [72.5]	21 100 [93.8]	18 100 [80.5]
9/16 [14.2]	12	0.182 [117]	19 650 [87.4]	18 150 [80.7]	22 700 [101]	20 400 [90.7]	26 500 [118]	22 700 [101]
5/8 [15.9]	11	0.226 [146]	23 900 [106]	22 050 [98.1]	27 550 [123]	24 800 [110]	32 150 [143]	27 550 [123]
3/4 [19]	10	0.334 [215]	33 650 [150]	31 050 [138]	38 850 [173]	34 950 [155]	45 300 [202]	38 850 [173]
7/8 [22.2]	9	0.462 [298]	44 300 [197]	40 900 [182]	51 100 [227]	46 600 [207]	59 650 [265]	51 100 [227]
1 [25.4]	8	0.606 [391]	55 150 [245]	50 900 [226]	63 650 [283]	57 300 [255]	74 250 [330]	63 650 [283]
1 1/8 [28.6]	8	0.790 [510]	68 000 [302]	62 800 [279]	78 500 [349]	70 650 [314]	91 600 [407]	78 500 [349]
1 1/4 [31.8]	8	1.000 [645]	81 250 [361]	75 000 [334]	93 750 [417]	84 400 [375]	109 350 [486]	93 750 [417]
1 3/8 [34.9]	8	1.233 [795]	94 250 [419]	86 950 [387]	108 750 [484]	97 800 [435]	126 850 [564]	108 750 [484]
1 1/2 [38.1]	8	1.492 [962]	106 700 [475]	98 500 [438]	123 100 [548]	110 800 [493]	143 600 [639]	123 100 [548]

[A] Based upon following equation (this equation cannot be used for extrapolating values beyond the size ranges listed in this table):

$$CPL = (1 - 0.30D) \times f \times As$$

where:

CPL = cone stripping proof load lbf [kN],
D = nominal diameter of nut, in. [mm],
f = minimum proof stress of nut, psi [MPa]; see footnotes *b, c, d, e,* and *f,*
As = tensile stress area of nut, in.^{2} = $0.7854 [D - 0.9743/n]^2$, and
n = threads per inch [25.4 mm].

[B] Based on proof stress of 130 000 psi [895 MPa].
[C] Based on proof stress of 120 000 psi [825 MPa].
[D] Based on proof stress of 150 000 psi [1035 MPa].
[E] Based on proof stress of 135 000 psi [930 MPa].
[F] Based on proof stress of 175 000 psi [1205 MPa].

ance with ANSI B1.1 and shall be gaged in accordance with ANSI B1.2 as described in 9.2.1 and 9.2.2.

9.2.1 Nuts up to and including 1 in. [25.4 mm] nominal size shall be UNC Series Class 2B fit.

9.2.2 Nuts over 1 in. [25.4 mm] nominal size shall be either UNC Series Class 2B fit or 8 UN Series Class 2B fit. Unless otherwise specified, the 8 UN series shall be furnished.

10. Workmanship, Finish, and Appearance

10.1 Nuts shall be free of defects and shall be good commercial finish.

10.2 If visible surface imperfections in size 1/4 thru 1 1/2 in. [6.4 thru 38.1 mm] and in any grade other than Grade 8 become a matter of issue between the manufacturer and the purchaser, the cone proof load test described in 7.3 shall be employed.

10.3 If a scale-free bright finish is required, this shall be specified on the purchase order.

11. Inspection

11.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless agreed otherwise.

12. Rejection

12.1 Unless otherwise specified, any rejection based on tests made in accordance with 6.4 shall be reported to the manufacturer within 30 days from the date of tests.

13. Certification

13.1 When agreed upon in writing between the manufacturer and the purchaser, a certification that the nuts were manufactured and tested in accordance with this specification may be the basis of acceptance of the nuts.

13.2 When specified on the order, the manufacturer shall supply a test report showing the results of the mechanical and/or macroetch inspection tests performed in accordance with this specification.

13.3 When required in the order, the chemical analysis requirements and the minimum tempering temperature for nuts of Grades 2H, 2HM, 3, 4, 6, 6F, 7, and 7M shall be furnished on the certification. See 6.2 for heat analysis

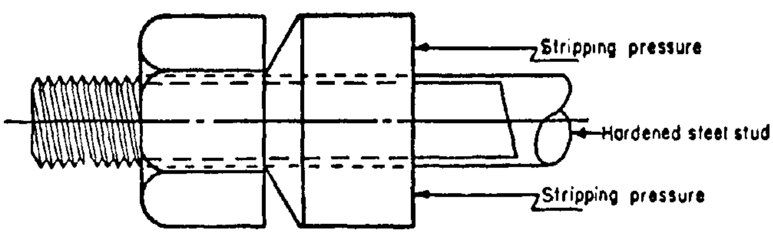

FIG. 1 Application of Hardened Steel Cone to Testing of Nuts

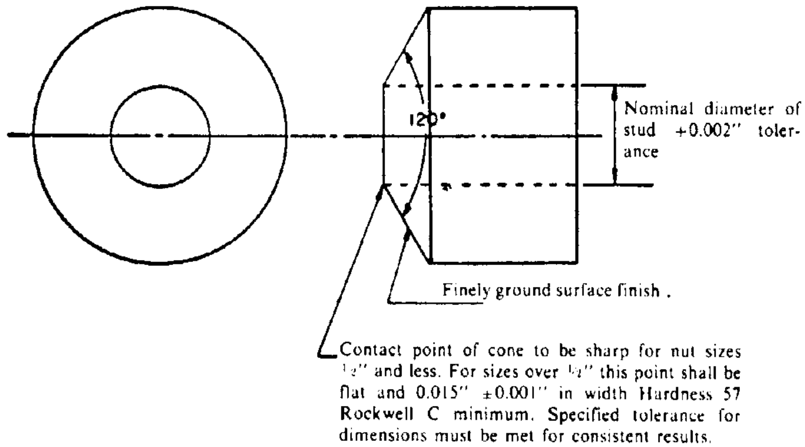

FIG. 2 Hardened Steel Cone

identification. (See Supplementary Requirement S2.)

14. Product Marking

14.1 All nuts shall bear the manufacturer's identification mark.

14.2 Nuts shall be legibly marked to indicate the grade and the process of the manufacturer, as prescribed in Table 5.

14.3 For purposes of identification marking, the manufacturer is considered the organization that certifies the fastener was manufactured, sampled, tested, and inspected in accordance with the specification and the results have been determined to meet the requirements of this specification.

TABLE 5 Marking of Nuts

Grade and Type	Nuts Hot-Forged or Cold-Punched	Nuts Machined from Bar Stock	Nuts Manufactured in Accordance with 5.7
1	1	B	. . .
2	2	2B	. . .
2H[A]	2H	2HB	. . .
2HM[A]	2HM	2HMB	. . .
3	3	3B	. . .
4	4	4B	. . .
6	6	6B	. . .
6F	6F	6FB	. . .
7	7	7B	. . .
7M[A]	7M	7MB	. . .
8	8	8B	8A
8C	8C	8CB	8CA
8M	8M	8MB	8MA
8T	8T	8TB	8TA
8F	8F	8FB	8FA
8P	8P	8PB	8PA
8N	8N	8NB	8NA
8MN	8MN	8MNB	8MNA
8R	8R	8RB	8RA
8S	8S	8SB	8SA
8LN	8LN	8LNB	8LNA
8MLN	8MLN	8MLNB	8MLNA

[A] The letters H and M indicate heat-treated nuts (see Section 5).

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. Strain-Hardened Austenitic Steel Nuts

S1.1 Grades 8, 8C, 8T, 8M, 8F, 8P, 8N, and 8MN nuts shall be machined from cold-drawn bars with no subsequent heat treatment. Nuts made in accordance with this section shall be marked with the underlined grade symbol. The hardness requirements of Table 2 will not apply.

S2. Chemical Composition Certification

S2.1 The purchaser shall be provided with a statement certifying that the nuts meet the chemical composition requirements specified in Table 1.

S3. Retests by Purchaser's Representative

S3.1 The purchaser's representative may select two nuts per keg (200-lb unit [90-kg]) for sizes ⅝ in. [15.9 mm] and smaller, one nut per keg for sizes over ⅝ in. [15.9 mm] up to and including 1½ in. [38.1 mm], and one nut per every two kegs for sizes larger than 1½ in. [38.1 mm], which shall be subjected to the tests specified in Section 7.

S4. Low-Temperature Requirements for (Grade 4 or) Grade 7 Nuts

S4.1 When low-temperature requirements are specified for Grade 4 or Grade 7 nuts, the Charpy test procedures and requirements as defined in Specification A 320 for Grade L7 shall apply. Depending on the size of nuts, separate test samples of the same heat may be required and shall be processed through heat treatment with the nuts for which the test is to apply. Full-size impact specimens cannot be obtained if the bar stock is smaller than ⅝ in. in diameter.

S5. Proof Load Tests of Large Nuts

S5.1 Proof load testing of nuts requiring proof loads of over 120 000 lbf [530 kN] may be required. When specified, the test is to be performed in accordance with 7.2 to the loads required by Table 6. The maximum load will be based entirely on the equipment available. For convenience, Table 6 lists up to 2¾–8 thread size.

S6. Control of Product by Heat Number

S6.1 When control of nuts by actual heat analysis is required and this supplementary requirement is specified, the manufacturer shall identify the completed nuts in each shipment by the actual heat number. When this supplementary requirement is specified, a certificate including the results of the actual production tests of each test lot together with the heat chemical analysis shall be furnished by the manufacturer.

TABLE 6 Proof Load for Large Heavy Hex Nuts[A]

Nominal Size, in. [mm]	Threads per in. [25.4 mm]	Stress Area, in.^{2} [mm^2]	Proof Load, lbf (kN)[B]		
			Grade 1 Heavy Hex	Grades 2, 6, 6F Heavy Hex	Grades 2H, 3, 4, 7 Heavy Hex
1⅝ [41.2]	8	1.78 [1148]	231 400 [1029]	267 000 [1188]	311 500 [1386]
1¾ [44.4]	8	2.08 [1342]	270 400 [1203]	312 000 [1388]	364 000 [1619]
1⅞ [47.6]	8	2.41 [1555]	313 300 [1394]	361 500 [1608]	421 800 [1876]
2 [50.8]	8	2.77 [1787]	360 100 [1602]	415 500 [1848]	484 800 [2156]
2¼ [57.2]	8	3.56 [2297]	462 800 [2059]	534 000 [2375]	623 000 [2771]
2½ [63.5]	8	4.44 [2864]	577 200 [2568]	666 000 [2962]	777 000 [3456]
2¾ [69.8]	8	5.43 [3503]	705 900 [3140]	814 500 [3623]	950 250 [4227]

[A] ANSI B18.2.2 in the size range over 1½ in. [38.1 mm] provides dimensions only for heavy hex nuts. Refer to 7.3.1.

[B] Proof loads for nuts of larger dimensions or other thread series may be calculated by multiplying the thread stress area times the proof stress in the notes to Table 3. The proof load for jam nuts shall be 46 % of the tabulated load.

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American Association
State Highway and
Transportation Officials
Standard AASHTO No.: M 164

Standard Specification for High-Strength Bolts for Structural Steel Joints[1]

This standard is issued under the fixed designation A 325; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope*

1.1 This specification[2] covers the chemical and mechanical requirements of various types of quenched and tempered steel bolts commonly known as "high-strength structural bolts," intended for use in structural joints that are covered under requirements of the Specifications for Structural Joints Using ASTM A 325 or A 490 Bolts,[3] issued by the Research Council on Structural Connections of the Engineering Foundation. Types of bolts covered in this specification are:

1.1.1 *Type 1*—Bolts made of medium-carbon steel, supplied in sizes ½ to 1½ in., inclusive, in diameter.

1.1.2 *Type 2*—Bolts made from what is generally described as low-carbon martensite steel, supplied in sizes ½ to 1.0 in., inclusive, in diameter.

1.1.3 *Type 3*—Bolts, ½ to 1½ in., inclusive, in diameter having atmospheric corrosion resistance and weathering characteristics comparable to that of the steels covered in Specifications A 242, A 588, and A 709 (these steels have atmospheric corrosion resistance approximately two times that of carbon structural steel with copper).

1.2 When the bolt type is not specified, either Type 1 or Type 2 may be supplied at the option of the manufacturer. Type 3 bolts may be supplied by the manufacturer if agreed by the purchaser. Where elevated temperature applications are involved, Type 1 bolts shall be specified by the purchaser on the order.

1.3 When atmospheric corrosion resistance is required, Type 3 bolts shall be specified by the purchaser in any inquiry or order.

NOTE 1—Bolts for general applications, including anchor bolts, are covered by Specification A 449. Also refer to Specification A 449 for quenched and tempered steel bolts and studs with diameters greater than 1½ in., but with similar mechanical properties.

1.4 This specification provides that heavy hex structural bolts shall be furnished unless other dimensional requirements are stipulated in the purchase inquiry and order (see S.1).

1.5 When zinc-coated high-strength structural bolts are specified, the bolts shall be either Type 1 or 2, at the manufacturer's option, unless otherwise ordered by the purchaser. Zinc-coated bolts and nuts shall be shipped in the same container.

1.6 Unless otherwise specified, all nuts used on these bolts shall conform to the requirements of Specification A 194 or A 563, shall be heavy hex, and shall be of the class and surface finish for each type of bolt as follows:

Bolt Type and Finish	Nut Class and Finish
1 and 2, plain (noncoated)	A 563 - C, C3, D, DH, DH3, plain A 194 - 2, 2H, plain
1 and 2, zinc coated	A 563 - DH, zinc coated A 194 - 2H, zinc coated
3, plain	A 563 - C3, DH3, plain

1.7 Unless otherwise specified, all washers used on these bolts shall conform to the requirements of Specification F 436 and shall be of a surface finish for each type of bolt as follows:

Bolt Type and Finish	Washer Finish
1 and 2, plain (uncoated)	plain (uncoated)
1 and 2, zinc coated	zinc coated
3, plain	weathering steel, plain

NOTE 2—A complete metric companion to Specification A 325 has been developed—Specification A 325M; therefore no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[4]

A 194/A 194M Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service[5]

A 242/A 242M Specification for High-Strength Low-Alloy Structural Steel[6]

A 449 Specification for Quenched and Tempered Steel Bolts and Studs[7]

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets, and Washers.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as A 325 – 64. Last previous edition A 325 – 89.

[2] For *ASME Boiler and Pressure Vessel Code* applications see related Specification SA-325 in Section II of that Code.

[3] Published by American Institute of Steel Construction, Wrigley Building, 400 N. Michigan Ave., Chicago, IL 60611.

[4] *Annual Book of ASTM Standards*, Vols 01.06 and 15.08.

[5] *Annual Book of ASTM Standards*, Vol 01.01.

[6] *Annual Book of ASTM Standards*, Vol 01.04.

[7] *Annual Book of ASTM Standards*, Vol 15.08.

* A Summary of Changes section appears at the end of this specification.

A 490 Specification for Heat-Treated, Steel Structural Bolts, 150 ksi (1035 MPa) Tensile Strength[7]
A 563 Specification for Carbon and Alloy Steel Nuts[7]
A 588 Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick[6]
A 709 Specification for Structural Steel for Bridges[6]
A 751 Methods, Practices, and Definitions for Chemical Analysis of Steel Products[8]
B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel[9]
D 3951 Practice for Commercial Packaging[10]
F 436 Specification for Hardened Steel Washers[7]
F 606 Test Methods for Determining the Mechanical Properties of Externally Threaded Fasteners, Washers, and Rivets[7]

2.2 *ANSI/ASME Standards:*[11]
B1.1 Unified Screw Threads
B18.2.1 Square and Hex Bolts and Screws

2.3 *Military Standard:*[12]
MIL-STD-105 Sampling Procedure and Tables for Inspection by Attributes

3. Ordering Information

3.1 Orders for products under this specification shall include the following:

3.1.1 Quantity (number of pieces of bolts and accessories),

3.1.2 Name of products, including accessories such as nuts and washers when desired,

3.1.3 *Zinc Coating*—Specify the zinc coating process required, for example, hot dip, mechanically deposited, or no preference (see 4.4.),

3.1.4 *Other Finishes*—Specify other protective finish if required,

3.1.5 Dimensions including nominal bolt diameter and length. For bolts of dimensional requirements other than heavy hex structural bolts (see 1.4) it is normally necessary to specify grip length,

3.1.5.1 Bolts threaded full length, specify Supplementary Requirement S1,

3.1.6 Type of bolt (that is, Type 1, 2 or 3). Note that Type 1 and 2 bolts may be shipped at the manufacturer's option if type has not been specified by the purchaser,

3.1.7 ASTM designation and year of issue,

3.1.8 Whether proof load tests are required, and

3.1.9 Specify if test reports are required (see 13.1).

3.1.10 Any special requirements.

NOTE 3—Two examples of ordering descriptions follow: (*1*) 1000 pieces, heavy hex structural bolts, each with one hardened washer, ASTM F 436 and one heavy hex nut, ASTM A 563 Grade DH, hot dip zinc coated, 1 by 4, ASTM A 325 - XX. (*2*) 1000 pieces, heavy hex structural bolts, no nuts or washers, ⅞ by 2¼ Type 1, ASTM A 325 - XX, for hot-dip zinc-coating.

4. Materials and Manufacture

4.1 Steel for bolts shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

4.2 Bolts shall be heat treated by quenching in a liquid medium from above the austenitizing temperature and then tempering by reheating to a temperature of at least 800°F.

4.3 Threads of bolts may be cut or rolled.

4.4 *Zinc Coatings, Hot-dip and Mechanically Deposited:*

4.4.1 When zinc-coated fasteners are required, the purchaser shall specify the zinc coating process, for example, hot dip, mechanically deposited, or no preference.

4.4.2 When hot-dip is specified, the fasteners shall be zinc-coated by the hot-dip process in accordance with the requirements of Class C of Specification A 153.

4.4.3 When mechanically deposited is specified the fasteners shall be zinc-coated by the mechanical deposition process in accordance with the requirements of Class 50 of Specification B 695.

4.4.4 When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with Specification A 153, Class C or a mechanically deposited zinc coating in accordance with Specification B 695, Class 50. All components of mating fasteners (for example, bolts, nuts, and washers) shall be coated by the same zinc-coating process and the suppliers option is limited to one process per item with no mixed processes in a lot.

4.4.5 Type 2 bolts shall be zinc-coated by the mechanical deposition process only.

4.5 If heat treatment is performed by a subcontractor the heat-treated material shall be returned to the manufacturer for testing.

4.6 If zinc coating is performed by a sub-contractor, all bolts shall be returned to the manufacturer for sampling and testing in accordance with 9.2.8.

5. Chemical Composition

5.1 Type 1 and 2 bolts shall conform to the requirements as to chemical composition prescribed in Table 1.

5.2 Type 3 bolts shall conform to one of the chemical compositions prescribed in Table 2. The selection of the chemical composition, A, B, C, D, E, or F, shall be at the option of the bolt manufacturer.

5.3 Product analyses may be made by the purchaser from

TABLE 1 Chemical Requirements for Types 1 and 2 Bolts

Element	Composition, %	
	Type 1 Bolts	Type 2 Bolts[A]
Carbon:		
Heat analysis	0.28–0.55	0.15–0.38
Product analysis	0.25–0.58	0.13–0.41
Manganese, min:		
Heat analysis	0.60	0.70
Product analysis	0.57	0.67
Phosphorus, max:		
Heat analysis	0.040	0.040
Product analysis	0.048	0.048
Sulfur, max:		
Heat analysis	0.050	0.050
Product analysis	0.058	0.058
Boron, min:		
Heat analysis	. . .	0.0005
Product analysis	. . .	0.0005

[A] Type 2 bolts shall be fully killed, fine grain steel.

[8] *Annual Book of ASTM Standards*, Vols 01.01–01.05.
[9] *Annual Book of ASTM Standards*, Vols 02.05 and 15.08.
[10] *Annual Book of ASTM Standards*, Vol 15.09.
[11] Available from the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.
[12] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

TABLE 2 Chemical Requirements for Type 3 Bolts

Element	Composition, % Type 3 Bolts[A] A	B	C	D	E	F
Carbon:						
Heat analysis	0.33–0.40	0.38–0.48	0.15–0.25	0.15–0.25	0.20–0.25	0.20–0.25
Product analysis	0.31–0.42	0.36–0.50	0.14–0.26	0.14–0.26	0.18–0.27	0.19–0.26
Manganese:						
Heat analysis	0.90–1.20	0.70–0.90	0.80–1.35	0.40–1.20	0.60–1.00	0.90–1.20
Product analysis	0.86–1.24	0.67–0.93	0.76–1.39	0.36–1.24	0.56–1.04	0.86–1.24
Phosphorus:						
Heat analysis	0.040 max	0.06–0.12	0.035 max	0.040 max	0.040 max	0.040 max
Product analysis	0.045 max	0.06–0.125	0.040 max	0.045 max	0.045 max	0.045 max
Sulfur:						
Heat analysis	0.050 max	0.050 max	0.040 max	0.050 max	0.040 max	0.040 max
Product analysis	0.055 max	0.055 max	0.045 max	0.055 max	0.045 max	0.045 max
Silicon:						
Heat analysis	0.15–0.35	0.30–0.50	0.15–0.35	0.25–0.50	0.15–0.35	0.15–0.35
Product analysis	0.13–0.37	0.25–0.55	0.13–0.37	0.20–0.55	0.13–0.37	0.13–0.37
Copper:						
Heat analysis	0.25–0.45	0.20–0.40	0.20–0.50	0.30–0.50	0.30–0.60	0.20–0.40
Product analysis	0.22–0.48	0.17–0.43	0.17–0.53	0.27–0.53	0.27–0.63	0.17–0.43
Nickel:						
Heat analysis	0.25–0.45	0.50–0.80	0.25–0.50	0.50–0.80	0.30–0.60	0.20–0.40
Product analysis	0.22–0.48	0.47–0.83	0.22–0.53	0.47–0.83	0.27–0.63	0.17–0.43
Chromium:						
Heat analysis	0.45–0.65	0.50–0.75	0.30–0.50	0.50–1.00	0.60–0.90	0.45–0.65
Product analysis	0.42–0.68	0.47–0.83	0.27–0.53	0.45–1.05	0.55–0.95	0.42–0.68
Vanadium:						
Heat analysis	...	...	0.020 min	...	...	...
Product analysis	...	...	0.010 min	...	...	...
Molybdenum:						
Heat analysis	...	0.06 max	...	0.10 max	...	...
Product analysis	...	0.07 max	...	0.11 max	...	...
Titanium:						
Heat analysis	...	...	...	0.05 max	...	...
Product analysis	...	...	...	...	...	...

[A] A, B, C, D, E, and F are classes of material used for Type 3 bolts. Selection of a class shall be at the option of the bolt manufacturer.

finished material representing each lot of bolts. The chemical composition thus determined shall conform to the requirements prescribed in 5.1 or 5.2.

5.4 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for bolts.

5.5 Chemical analyses shall be performed in accordance with Methods, Practices, and Definitions A 751.

6. Mechanical Properties

6.1 *Tensile and Hardness Tests, All Products:*

6.1.1 Bolts shall not exceed the maximum hardness specified in Table 3. Bolts less than three diameters in length shall have hardness values not less than the minimum nor more than the maximum in hardness limits required in Table 3, as hardness is the only requirement.

6.1.2 Bolts 1½ in. in diameter or less, other than those excepted in 6.1.1, shall be tested full size and shall conform to the tensile strength requirements as specified in Table 4. The proof load test is not a mandatory production test. When specified on the inquiry and order, the bolts shall be tested to either the proof load or alternative proof load requirements specified in Table 4 in addition to the tensile strength requirements. In case of controversy the bolts shall be capable of conforming to the proof load requirements in addition to all other requirements.

TABLE 3 Hardness Requirements for Bolts

Bolt Size, in.	Hardness Number Brinell Min	Max	Rockwell C Min	Max
½ to 1, incl	248	331	24	35
1⅛ to 1½, incl	223	293	19	31

6.1.3 Bolts larger than 1½ in. in diameter, other than those excepted in 6.1.1, shall preferably be tested full size and when so tested shall conform to the tensile strength and either the proof load or alternative proof load requirements specified in Table 4. When equipment of sufficient capacity for full-size testing is not available, or when the length of the bolt makes full-size testing impractical, machined specimens

TABLE 4 Tensile Requirements for Full Size Bolts

Bolt Size, Threads per Inch and Series Designation	Stress Area,[A] in.²	Tensile Strength[B] min, lbf	Proof Load,[B] Length Measurement Method	Alternative Proof Load,[B] Yield Strength Method, min
Column 1	Column 2	Column 3	Column 4	Column 5
½-13 UNC	0.142	17 050	12 050	13 050
⅝-11 UNC	0.226	27 100	19 200	20 800
¾-10 UNC	0.334	40 100	28 400	30 700
⅞-9 UNC	0.462	55 450	39 250	42 500
1-8 UNC	0.606	72 700	51 500	55 750
1⅛-7 UNC	0.763	80 100	56 450	61 800
1⅛-8 UN	0.790	82 950	58 450	64 000
1¼-7 UNC	0.969	101 700	71 700	78 500
1¼-8 UN	1.000	105 000	74 000	81 000
1⅜-6 UNC	1.155	121 300	85 450	93 550
1⅜-8 UN	1.233	129 500	91 250	99 870
1½-6 UNC	1.405	147 500	104 000	113 800
1½-8 UN	1.492	156 700	110 400	120 850

[A] The stress area is calculated as follows:

$$As = 0.7854\,[D - (0.9743/n)]^2$$

where:
As = stress area, in.²,
D = nominal bolt size, and
n = threads per inch.

[B] Loads tabulated are based on the following:

Bolt Size, in.	Column 3	Column 4	Column 5
½ to 1, incl	120 000 psi	85 000 psi	92 000 psi
1⅛ to 1½, incl	105 000 psi	74 000 psi	81 000 psi

TABLE 5 Tensile Requirements for Specimens Machined from Bolts

Bolt Size, in.	Tensile Strength, min, psi	Yield Strength (0.2 % Offset) min, psi	Elongation in 2 in., min, %	Reduction of Area, min, %
1¼, 1⅜ and 1½	105 000	81 000	14	35

TABLE 6 Rotational Capacity Test for Zinc-Coated Bolts

Bolt Length, in.	Nominal Nut Rotation, ° (turn)
Up to and including 4	300 (⅚)
Over 4, but not exceeding 8	360 (1)
Over 8	420 (1⅙)

shall be tested and shall conform to the requirements of Table 5. In the event that bolts are tested by both full-size and by the machined test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

6.1.4 For bolts on which hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence in the event that there is controversy over low readings of hardness tests.

6.2 *Rotational Capacity* (*Lubricant*) *Test:*

6.2.1 In addition, when zinc-coated bolts and nuts are supplied, the bolt/nut assembly shall be tested full size in an assembled joint as specified in 8.5. This rotational-capacity test is to determine the efficiency of the lubricant specified in the last paragraph of the Manufacturing Processes section of Specification A 563. The test shall be performed after the bolts and nuts are zinc-coated, and the nuts lubricated, prior to shipment. For this test only the nut component, not the bolt, is lubricated.

6.2.2 After the rotational capacity test, the assembly shall show no signs of failure. Failure is defined as: (*1*) inability to assemble to the nut rotation specified in Table 6 or by an inability to remove the nut following the test, (*2*) shear failure of threads as determined by visual examination of bolt and nut threads following removal, and (*3*) torsional failure of the bolt. Elongation of bolt, in the threads between the nut and bolt head, is to be expected at the required rotation and is not to be classified as a failure.

7. Dimensions

7.1 Bolts with hex heads shall be full-body bolts conforming to the dimensions for heavy hex structural bolts specified in ANSI/ASME B18.2.1 (see S1).

7.2 Threads shall be the Unified Coarse Thread Series as specified in ANSI/ASME B1.1, and shall have Class 2A tolerances. When specified, 8-pitch thread series may be used on bolts over 1 in. in diameter.

7.3 Unless otherwise specified, bolts to be used with nuts or tapped holes which have been tapped oversize, in accordance with Specification A 563, shall have Class 2A threads before hot-dip or mechanically deposited zinc coating. After zinc coating, the maximum limit of pitch and major diameter may exceed the Class 2A limit by the following amount:

Diameter, in.[A]	Oversize Limit, in.[A]
Up to 7/16, incl	0.016
Over 7/16 to 1, incl	0.021
Over 1	0.031

[A] These values are the same as the minimum overtapping required for zinc-coated nuts in Specification A 563.

7.4 The gaging limit for bolts shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gage of that same size (Class X tolerance, gage tolerance plus) is to be used. Assembly of the gage, or the nut described above, must be possible with hand effort following application of light machine oil to prevent galling and damage to the gage. These inspections, when performed to resolve disputes, are to be performed at the frequency and quality described in Table 7.

8. Test Methods

8.1 Tests shall be conducted in accordance with Method F 606.

8.2 For tension tests a proof load determination is preferred conducted in accordance with Method 1, Length Measurement, of Test Methods F 606.

8.3 Bolts tested in full size shall be tested in accordance with the wedge test method described in the Wedge Tension Testing of Full-Size Product paragraph of Test Methods F 606. Fracture shall be in the body or threads of the bolt, without any fracture at the junction of the head and body.

8.4 The speed of testing as determined with a free-running cross head shall be a maximum of ⅛ in./min for the bolt proof-load determination, and a maximum of 1 in./min for the bolt tensile-strength determination.

8.5 The zinc-coated bolt shall be placed in a steel joint and assembled with a zinc-coated washer and a zinc-coated

TABLE 7 Sample Sizes and Acceptance Numbers for Inspection of Hot Dip or Mechanically Deposited Zinc-Coated Threads

Lot Size	Sample Size[A,B]	Acceptance Number[A]
2 to 90	13	1
91 to 150	20	2
151 to 280	32	3
281 to 500	50	5
501 to 1 200	80	7
1 201 to 3 200	125	10
3 201 to 10 000	200	14
10 001 and over	315	21

[A] Sample sizes of acceptance numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105.
[B] Inspect all bolts in the lot if the lot size is less than the sample size.

nut with which the bolt is intended to be used. The nut shall have been provided with the lubricant described in the last paragraph of the Manufacturing Processes section of Specification A 563. The joint shall be one or more flat structural steel plates with a total thickness, including the washer, such that 3 to 5 full threads of the bolt are located between the bearing surfaces of the bolt head and nut. The hole in the joint shall have the same nominal diameter as the hole in the washer. The initial tightening of the nut shall produce a load in the bolt not less than 10 % of the specified proof load.[13] After initial tightening, the nut position shall be marked relative to the bolt, and the rotation shown in Table 6 shall be applied. During rotation, the bolt head shall be restrained from turning.

9. Quality Assurance of Mechanical Requirements

9.1 The manufacturer shall make sample inspections of every lot of bolts to ensure that properties of bolts are in conformance with the requirements of this specification. All bolts shall be inspection tested prior to shipment in accordance with one of the two quality assurance procedures described in 9.2 and 9.3, respectively. The manufacturer shall have the option of which procedure will be followed when furnishing bolts to any single purchase order.

9.1.1 The purpose of a lot inspection testing program is to ensure that each lot conforms to the requirements of this specification. For such a plan to be fully effective it is essential that following delivery the purchaser continue to maintain the identification and integrity of each lot until the product is installed in its service application.

9.2 *Production Lot Method:*

9.2.1 All bolts shall be processed in accordance with a lot identification-control quality assurance plan. The manufacturer shall identify and maintain the integrity of each production lot of bolts from raw-material selection through all processing operations and treatments to final packing and shipment. Each lot shall be assigned its own lot-identification number, each lot shall be tested, and the inspection test reports for each lot shall be retained.

9.2.2 A production lot, for purposes of assigning an identification number and from which test samples shall be selected, shall consist of all bolts processed essentially together through all operations to the shipping container that are of the same nominal size, the same nominal length, and produced from the same mill heat of steel.

9.2.3 The manufacturer shall make tests for tensile strength (wedge test) and hardness of each lot of bolts. Alternatively, in accordance with 6.1.3, tests may be tensile strength, yield strength, reduction of area, elongation, and hardness.

9.2.4 From each production lot, the minimum number of tests of each required property shall be as follows:

Number of Pieces in Production Lot	Number of Specimens
800 and less	1
801 to 8 000	2
8 001 to 35 000	3
35 001 to 150 000	8
150 001 and over	13

9.2.5 If any test specimen shows defective machining it may be discarded and another specimen substituted.

9.2.6 Bolts shall be packed in shipping containers as soon as practicable following final processing. Shipping containers shall be marked with the lot identification number.

9.2.7 A copy of the inspection test report for each production lot from which bolts are supplied to fill the requirements of a shipment shall be furnished to the purchaser when specified in the order. Individual heats of steel need not be identified on the test report.

9.2.8 In the case of zinc coated bolts, the rotational capacity test shall be performed at the rate of two assemblies per lot.

9.2.9 When tested in accordance with the required sampling plan, a lot shall be rejected if any of the test specimens fail to meet the applicable test requirements.

9.3 *Shipping Lot Method:*

9.3.1 In-process inspection during all manufacturing operations and treatments and storage of manufactured bolts shall be in accordance with the practices of the individual manufacturer.

9.3.2 Before packing bolts for shipment, the manufacturer shall make tests of sample bolts taken at random from each shipping lot. A shipping lot, for purposes of selecting test samples, is defined as that quantity of bolts of the same nominal size and same nominal length necessary to fill the requirements of a single purchase order.

9.3.3 The manufacturer shall make tests for tensile strength (wedge test) and hardness of each lot of bolts, including proof load tests when specified on the order. Alternatively, in accordance with 6.3, tests may be tensile strength, yield strength, reduction of area, elongation, and hardness.

9.3.4 From each shipping lot, the minimum number of tests of each required property shall be as follows:

Number of Pieces in Shipping Lot	Number of Specimens
150 and less	1
151 to 280	2
281 to 500	3
501 to 1 200	5
1 201 to 3 200	8
3 201 to 10 000	13
10 001 and over	20

9.3.5 If any test specimen shows defective machining it may be discarded and another specimen substituted.

9.3.6 A copy of the inspection test report for each shipping lot shall be furnished to the purchaser when

[13] Use of the torque value obtained in a Skidmore-Wilhelm calibrator, or equivalent, may be used in meeting this requirement.

specified in the order. Individual heats of steel are not identified in the finished product.

9.3.7 In the case of zinc coated bolts, the rotational capacity test shall be performed at the rate of two assemblies per lot.

9.3.8 When tested in accordance with the required sampling plan, a lot shall be rejected if any of the test specimens fail to meet the applicable test requirements.

10. Visual Inspection for Head Bursts

10.1 A burst is an open break in the metal (material). Bursts can occur on the flats or corners of the heads of bolts.

10.2 A defective bolt, for the purposes of the visual inspection for bursts, shall be any bolt that contains a burst in the flat of the head which extends into the top crown surface of the head (chamfer circle) or the under-head bearing surface. In addition, bursts occurring at the intersection of two wrenching flats shall not reduce the width across corners below the specified minimum.

10.3 A lot, for the purposes of visual inspection, shall consist of all bolts of one type having the same nominal diameter and length offered for inspection at one time.

10.4 From each lot of bolts, a representative sample shall be picked at random and visually inspected for bursts. The sample size shall be as shown in Table 8. If the number of defective bolts found during inspection by the manufacturer is greater than the acceptance number given in Table 8 for the sample size, all bolts in the lot shall be visually inspected and all defective bolts shall be removed and destroyed. If the number of defective bolts found during inspection by the purchaser is greater than the acceptance number given in Table 8 for the sample size, the lot shall be subject to rejection.

11. Inspection

11.1 If the inspection described in 11.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

11.2 The inspector representing the purchaser shall have free entry to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specification that are requested by the purchaser's representative shall be made before shipment, and shall be conducted as not to interfere unnecessarily with the operation of the works.

TABLE 8 Sample Sizes with Acceptance and Rejection Numbers for Inspection of Bursts 2.5 AQL

Lot Size	Sample Size[A, B]	Acceptance Number[A]	Rejection No.
2 to 8	2	0	1
9 to 15	3	0	1
16 to 25	5	0	1
26 to 150	20	1	2
151 to 280	32	2	3
281 to 500	50	3	4
501 to 1 200	80	5	6
1 201 to 3 200	125	7	8
3 201 to 10 000	200	10	11
10 001 to 35 000	315	14	15

[A] Sample sizes, acceptance numbers, and rejection numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105.

[B] Inspect all bolts in the lot if the lot size is less than the sample size.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

13. Certification

13.1 *Bolts*—When specified on the order the manufacturer shall furnish the test reports described in 9.2.7 or 9.3.6, depending on whether the bolts are furnished by the production lot or shipping lot method.

14. Responsibility

14.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser and certifies that the fastener was manufactured, sampled, tested and inspected in accordance with this specification and meets all of its requirements.

15. Product Marking

15.1 All bolts, Types 1, 2 and 3, shall be marked A 325 and shall also be marked with a symbol identifying the manufacturer.

15.2 In addition Type 1 bolts may, at the option of the manufacturer, be marked with three radial lines 120° apart.

15.3 In addition Type 2 bolts shall be marked with three radial lines 60° apart.

15.4 In addition Type 3 bolts shall have the A 325 *underlined*, and the manufacturer may add other distinguishing marks indicating that the bolt is atmospheric corrosion resistant and of a weathering type.

15.5 All markings shall be located on the top of the bolt head and may be either raised or depressed, at the option of the manufacturer.

16. Packaging and Package Marking

16.1 *Packaging:*

16.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

16.1.2 When zinc coated nuts are included on the same order as zinc coated bolts, the bolts and nuts shall be shipped in the same container.

16.1.3 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

16.2 *Package Marking:*

16.2.1 Each shipping unit shall include or be plainly marked with the following information:

16.2.1.1 ASTM designation and type,

16.2.1.2 Size,

16.2.1.3 Name and brand or trademark of the manufacturer,

16.2.1.4 Number of pieces,

16.2.1.5 Lot number,

16.2.1.6 Purchase order number, and

16.2.1.7 Country of origin.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order. Details of these supplementary requirements shall be agreed upon in writing between the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S.1 Bolts Threaded Full Length

S1.1 Bolts with nominal lengths equal to or shorter than four times the nominal bolt diameter shall be threaded full length. Bolts need not have a shoulder, and the distance from the underhead bearing surface to the first complete (full form) thread, as measured with a GO thread ring gage, assembled by hand as far as the thread will permit, shall not exceed the length of 2½ threads for bolt sizes 1 in. and smaller, and 3½ threads for bolt sizes larger than 1 in.

S1.2 Bolts shall be marked in accordance with Section 15, except that the symbol shall be A 325 T instead of A 325.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this specification that have been incorporated since the last issue. For the convenience of the user, Committee F 16 has highlighted those changes that may impact the use of this specification. This section may also include descriptions of the changes or reasons for the changes, or both.

(1) Added paragraph 14.1 Packaging in accordance with Practice D 3951 and paragraph 14.2 Package Marking.

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If not listed in the current combined index, will appear in the next edition.

Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength[1]

This standard is issued under the fixed designation A 490; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope*

1.1 This specification covers the chemical and mechanical requirements of heat-treated steel bolts, ½ to 1½ in., incl, in diameter. These bolts are intended for use in structural joints that are made under the Specification for Structural Joints Using ASTM A 325 or A 490 Bolts[2] issued by the Research Council on Structural Connections of the Engineering Foundation. The various types of bolts covered by this specification are:

1.1.1 *Type 1*—Bolts made of alloy steel, supplied in sizes ½ to 1½ in., inclusive, in diameter.

1.1.2 *Type 2*—Bolts made from what is generally described as low-carbon martensite steel, supplied in sizes ½ to 1 in., inclusive, in diameter.

1.1.3 *Type 3*—Bolts ½ to 1½ in., inclusive, in diameter having atmospheric corrosion resistance and weathering characteristics comparable to that of the steels covered in Specifications A 588, A 242, and A 709 (these steels have atmospheric corrosion resistance approximately two times that of carbon structural steel with copper).

1.2 The purchaser should specify either Type 1, 2, or 3 bolts. When the bolt type is not specified, Type 1, 2, or 3 may be furnished at the option of the manufacturer.

1.3 When atmospheric corrosion resistance and weathering characteristics are required, Type 3 bolts should be specified by the purchaser.

1.4 Unless otherwise specified, all nuts used on these bolts shall conform to the requirements of Specification A 194 or A 563, shall be heavy hex, and shall be of the class and surface finish for each type of bolt as follows:

Bolt Type and Finish	Nut Class and Finish
1 and 2, plain (noncoated)	A 563 - DH, DH3, plain A 194 - 2H, plain
3, plain	A 563 - DH3, plain

1.5 Unless otherwise specified, all washers used on these bolts shall conform to the requirements of Specification F 436 and shall be of a surface finish for each type of bolt as follows:

Bolt Type and Finish	Washer Finish
1 and 2, plain (uncoated)	plain (uncoated)
3, plain	weathering steel, plain

1.6 This specification provides that heavy hex structural bolts shall be furnished unless other dimensional requirements are stipulated in the purchase inquiry and order.

NOTE 1—For quenched and tempered alloy steel bolts, studs, and other externally threaded fasteners with diameters greater than 1½ in., but with similar mechanical properties, refer to Grade BD of Specification A 354.

NOTE 2—A complete metric companion to Specification A 490 has been developed—Specification A 490M; therefore no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 194 Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service[3]

A 242 Specification for High-Strength Low-Alloy Structural Steel[4]

A 325 Specification for High-Strength Bolts for Structural Steel Joints[5]

A 354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners[3]

A 563 Specification for Carbon and Alloy Steel Nuts[3]

A 588 Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick[4]

A 709 Specification for Structural Steel for Bridges[4]

A 751 Methods, Practices, and Definitions for Chemical Analysis of Steel Products[6]

D 3951 Practice for Commercial Packaging[7]

E 138 Method for Wet Magnetic Particle Inspection[8]

E 709 Practice for Magnetic Particle Examination[9]

F 436 Specification for Hardened Steel Washers[5]

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets, and Washers.

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[2] Published by the American Institute of Steel Construction, Wrigley Building, 400 N. Michigan Ave., Chicago, IL 60611.

[3] *Annual Book of ASTM Standards*, Vols 01.01 and 15.08.

[4] *Annual Book of ASTM Standards*, Vol 01.04.

[5] *Annual Book of ASTM Standards*, Vol 15.08.

[6] *Annual Book of ASTM Standards*, Vols 01.01, 01.02, 01.03, 01.04, and 01.05.

[7] *Annual Book of ASTM Standards*, Vol 15.09.

[8] Discontinued; see 1980 *Annual Book of ASTM Standards*, Part 11.

[9] *Annual Book of ASTM Standards*, Vol 03.03.

*** A Summary of Changes Section appears at the end of this specification.**

TABLE 1 Chemical Requirements for Type 1 Bolts

Element	Heat Analysis, %	Product Analysis, %
Carbon		
For sizes through 1⅜ in.	0.30–0.48	0.28–0.50
For size 1½ in.	0.35–0.53	0.33–0.55
Phosphorus, max	0.040	0.045
Sulfur, max	0.040	0.045
Alloying Elements ←	→ See 6.1	

F 606 Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets[5]

2.2 *ANSI Standards:*

B1.1 Unified Screw Threads[10]

B18.2.1 Square and Hex Bolts and Screws[10]

2.3 *Military Standard:*

MIL-STD-105 Sampling Procedure and Tables for Inspection by Attributes[11]

3. Terminology

3.1 *Definitions:*

3.1.1 Surface discontinuities covered in this specification are defined as follows:

3.1.1.1 *acceptable quality level* (AQL)—as defined in MIL-STD-105, the maximum percent defective that, for purposes of sampling inspection, can be considered satisfactory as the process average.

3.1.1.2 *burst*—a break located at the periphery of the bolt head.

3.1.1.3 *crack*—a clean crystalline break passing through the grain boundary without inclusion of foreign elements.

3.1.1.4 *process average*—as defined in MIL-STD-105, the average percent defective of product at the time of original inspection. Original inspection is that first inspection of a particular quantity of product which is being reinspected after rejection and reconditioning.

3.1.1.5 *seam or lap*—a noncrystalline break through the metal which is inherent in the raw material.

4. Ordering Information

4.1 Orders for products under this specification shall include the following:

4.1.1 Quantity (number of pieces of bolts and accessories),

4.1.2 Name of products, including accessories such as nuts and washers when desired,

4.1.3 Dimensions, including nominal bolt diameter and length. For bolts of dimensional requirements other than heavy hex structural bolts (see 1.6) it is normally necessary to specify grip length,

4.1.4 Type of bolt (that is, Type 1, 2, or 3). Note that Type 1, 2, or 3 bolts may be supplied by the manufacturer when bolt type is not specified,

4.1.5 ASTM designation and year of issue,

4.1.6 Whether proof load tests are required, and

4.1.7 Any special requirements.

[10] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

[11] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

TABLE 2 Chemical Requirements for Type 2 Bolts

Element	Heat Analysis, %	Product Analysis, %
Carbon	0.15–0.34	0.13–0.37
Manganese, min	0.70	0.67
Phosphorus, max	0.040	0.048
Sulfur, max	0.050	0.058
Boron, min	0.0005	0.0005

TABLE 3 Chemical Requirements for Type 3 Bolts

Element	Heat Analysis, %	Product Analysis, %
Carbon	0.20–0.53	0.19–0.55
Manganese, min	0.40	0.37
Phosphorus, max	0.040	0.045
Sulfur, max	0.050	0.055
Copper, max	0.60	0.63
Chromium, min	0.45	0.42
Nickel, min or	0.20	0.17
Molybdenum, min	0.15	0.14

NOTE 3—Two examples of ordering descriptions follow: (*1*) 1000 pieces, heavy hex structural bolts, each with two hardened washers, ASTM F 436, and one heavy hex nut, ASTM A 563 Grade DH, 1 by 4, ASTM A 490-XX. (*2*) 1000 pieces, heavy hex structural bolts, no nuts or washers, ⅞ by 2¼ Type 1, ASTM A 490-XX.

5. Materials and Manufacture

5.1 Steel shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

5.2 Type 1 bolts shall be heat treated by quenching in oil from above the transformation temperature. Type 2 and Type 3 bolts shall be quenched in a suitable liquid from above the transformation temperature. Type 1 and Type 3 bolts shall be tempered by reheating to a temperature of not less than 800°F. Type 2 bolts shall be tempered by reheating to a temperature of not less than 650°F. If heat treatment is performed by a subcontractor, the heat-treated material shall be returned to the manufacturer for testing.

5.3 Threads of bolts may be cut or rolled.

6. Chemical Composition

6.1 Type 1 bolts shall be made from alloy steel conforming to the chemical composition requirements given in Table 1. The steel shall contain sufficient alloying elements to qualify it as an alloy steel.

NOTE 4—Steel is considered to be alloy, by the American Iron and Steel Institute, when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65 %; silicon, 0.60 %; copper, 0.60 %; or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels: aluminum, chromium up to 3.99 %, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying elements added to obtain a desired alloying effect.

6.2 Type 2 bolts shall be made from steel conforming to the chemical composition requirements given in Table 2.

6.3 Type 3 bolts shall be made from steel conforming to the chemical composition requirements given in Table 3 and having atmospheric corrosion resistance approximately two times that of carbon steel with copper as required in 1.1.3.

6.4 Product analyses may be made by the purchaser from finished material representing each lot of bolts. The chemical

TABLE 4 Hardness Requirements for Bolts

Bolt Size, in.	Hardness Number			
	Brinell		Rockwell C	
	min	max	min	max
½ to 1½, incl	311	352	33	38

composition thus determined shall conform to the requirements given in Tables 1, 2, or 3, as applicable.

6.5 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for bolts.

6.6 Chemical analyses shall be performed in accordance with Methods, Practices, and Definitions A 751.

7. Mechanical Properties

7.1 *Product Hardness:*

7.1.1 Bolts less than three diameters in length shall conform to the minimum and maximum hardness limits specified in Table 4, as hardness is the only requirement. All bolts, regardless of diameter or length, shall conform to the maximum hardness specified in Table 4.

7.2 *Tensile Properties:*

7.2.1 Bolts 1¼ in. in diameter or less, other than those excepted in 7.1, shall be wedge tested full size and conform to the minimum and maximum tensile strength requirements as specified in Table 5.

7.2.2 Bolts larger than 1¼ in. in diameter, other than those excepted in 7.1, shall preferably be wedge tested full size and when so tested, shall conform to the minimum and maximum tensile strength requirements as specified in Table 5. When equipment of sufficient capacity for full-size testing is not available, or when the length of the bolt makes full-size testing impractical, machined specimens shall be tested and shall conform to the requirements of Table 6. In the event that bolts are tested by both full-size and by the machined test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

7.2.3 The proof load test is not a mandatory production test. When specified on the inquiry and order, the bolts shall be tested to either the proof load or alternative proof load requirements specified in Table 5 in addition to the tensile strength requirements. In case of controversy the bolts shall be capable of conforming to the proof load requirements in addition to all other requirements.

7.3 For bolts on which hardness and tension tests are performed, acceptance based on tensile requirements shall take precedence in the event that there is controversy over low readings of hardness tests.

7.4 *Surface Hardness:*

7.4.1 All sizes are subject to surface hardness requirements to control carburization. Surface hardness of bolts as taken at a maximum of 0.003 in. from the surface shall not be more than the equivalent of 3 points Rockwell C higher than the hardness taken at a distance of ⅛ in. from the surface. Both hardness readings shall be taken on the same axial longitudinal section through the threaded length of the bolt, shall be taken at the same time, and the same hardness scale shall be used.

8. Dimensions

8.1 Unless otherwise specified, bolts shall conform to the dimensions for heavy hex structural bolts specified in ANSI B18.2.1.

8.2 Threads shall be the Unified Coarse Thread Series as specified in ANSI B1.1, and shall have Class 2A tolerances. When specified, 8 pitch thread series shall be used on bolts over 1 in. in diameter.

9. Quality Assurance of Mechanical Properties

9.1 The manufacturer shall make sample inspections of every lot of bolts to ensure that properties of bolts are in conformance with the requirements of this specification. All bolts shall be inspected tested prior to shipment in accordance with one of the two quality assurance procedures described in 9.3 and 9.4, respectively. The manufacturer shall have the option of which procedure will be followed when furnishing bolts to any single purchase order.

9.2 The purpose of a lot inspection testing program is to ensure that each lot conforms to the requirements of this specification. For such a plan to be fully effective, it is essential that following delivery the purchaser continue to maintain the identification and integrity of each lot until the product is installed in its service application.

9.3 *Production Lot Method:*

9.3.1 All bolts shall be processed in accordance with a lot-identification-control quality assurance plan. The manufacturer shall identify and maintain the integrity of each production lot of bolts from raw-material selection through all processing operations and treatments to final packing and shipment. Each lot shall be assigned its own lot-identification number, each lot shall be tested, and the inspection test reports for each lot shall be retained.

9.3.2 A production lot, for purposes of assigning an identification number and from which test samples shall be selected, shall consist of all bolts processed essentially together through all operations to the shipping container that are of the same nominal size, the same nominal length, and produced from the same mill heat of steel.

9.3.3 The manufacturer shall test each lot of bolts for (1) product hardness (7.1), in accordance with Test Method F 606; (2) full-size wedge-test tensile strength or machined specimen tensile properties depending on size and length as required by 7.2; and (3) surface hardness (7.4). Proof load tests shall be conducted only when specified on the purchase order.

9.3.4 From each production lot, the minimum number of tests of each required property shall be in accordance with Table 7.

9.3.5 If any test specimen shows defective machining, it may be discarded and another specimen substituted.

9.3.6 Bolts shall be packed in shipping containers as soon as practicable following final processing. Shipping containers shall be marked with the lot identification number.

9.3.7 A copy of the inspection test report for each production lot from which bolts are supplied to fill the requirements of a shipment shall be furnished to the purchaser when specified in the order. Individual heats of steel need not be identified on the test report.

TABLE 5 Tensile Requirements for Full-Size Bolts

Bolt Size, Threads per Inch, and Series Designation	Stress Area,[A] in.^{2}	Tensile Load,[B] lbf		Proof Load,[B] lbf	Alternative Proof Load,[B] min, lbf
		min	max	Length Measurement Method	Yield Strength Method
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
½-13 UNC	0.142	21 300	24 150	17 050	18 500
⅝-11 UNC	0.226	33 900	38 400	27 100	29 400
¾-10 UNC	0.334	50 100	56 800	40 100	43 400
⅞-9 UNC	0.462	69 300	78 550	55 450	60 100
1-8 UNC	0.606	90 900	103 000	72 700	78 800
1⅛-7 UNC	0.763	114 450	129 700	91 550	99 200
1⅛-8 UN	0.790	118 500	134 300	94 800	102 700
1¼-7 UNC	0.969	145 350	164 750	116 300	126 000
1¼-8 UN	1.000	150 000	170 000	120 000	130 000
1⅜-6 UNC	1.155	173 250	196 350	138 600	150 200
1⅜-8 UN	1.233	185 000	209 600	148 000	160 300
1½-6 UNC	1.405	210 750	238 850	168 600	182 600
1½-8 UN	1.492	223 800	253 650	175 050	194 000

[A] The stress area is calculated as follows:

$$A_s = 0.7854\ [D - (0.9743/n)]^2$$

where:
A_s = stress area, in.^{2},
D = nominal bolt size, and
n = threads per inch.

[B] Loads tabulated and loads to be used for tests of full-size bolts larger than 1½ in. in diameter are based on the following:

Bolt Size	Column 3	Column 4	Column 5	Column 6
½ to 1½ in., incl	150 000 psi	170 000 psi	120 000 psi	130 000 psi

9.4 *Shipping Lot Method:*

9.4.1 In-process inspection during all manufacturing operations and treatments and storage of manufactured bolts shall be in accordance with the practices of the individual manufacturer.

9.4.2 Before packing bolts for shipment, the manufacturer shall make tests of sample bolts taken at random from each shipping lot. A shipping lot, for purposes of selecting test samples, is defined as that quantity of bolts of the same nominal size and same nominal length necessary to fill the requirements of a single purchase order.

9.4.3 The manufacturer shall test each lot of bolts for (1) product hardness (7.1), in accordance with Test Method F 606; (2) full size wedge test tensile strength or machined specimen tensile properties depending on size and length as required by 7.2; and (3) surface hardness (7.4). Proof load tests shall be conducted only when specified on the purchase order.

9.4.4 From each shipping lot, the minimum number of tests of each required property shall be in accordance with Table 8.

9.4.5 If any test specimen shows defective machining, it may be discarded and another specimen substituted.

TABLE 6 Tensile Requirements for Specimens Machined from Bolts

Bolt Size, in.	Tensile Strength, psi		Yield Strength (0.2 % offset), min, psi	Elongation in 2 in. or 50 mm, min, %	Reduction of Area, min, %
	min	max			
½ to 1½ in., incl	150 000	170 000	130 000	14	40

9.4.6 A copy of the inspection test report for each shipping lot shall be furnished to the purchaser when specified in the order. Individual heats of steel are not identified in the finished product.

10. Test Methods

10.1 Tests shall be conducted in accordance with Test Methods F 606.

10.2 Proof load testing of bolts tested in full size shall preferably be conducted in accordance with Method 1, Length Measurement, described in the section, Test Methods for Externally Threaded Fasteners, of Test Methods F 606.

10.3 Bolts tested in full size shall be tested in accordance with the Wedge Test method described in Wedge Tension Testing of Full-Size Product paragraph, of Test Methods F 606. Fracture shall be in the body or threads of the bolt, without any fracture at the junction of the head and body.

10.4 Machined specimens shall be tested in accordance with the method described in the paragraphs on Tension Testing of Machine Test Specimens, of Test Methods F 606.

TABLE 7 Production Lot Sample Size With Acceptance and Rejection Numbers for Inspection of Mechanical and Dimensional Requirements

Lot Size	Sample Size	Acceptance Number	Rejection Number
25 and less	2	0	1
26 to 150	3	0	1
151 to 1 200	5	0	1
1 201 to 35 000	8	0	1
35 001 to 150 000	13	0	1
150 001 and over	20	0	1

TABLE 8 Shipping Lot Sample Size With Acceptance and Rejection Numbers for Inspection of Mechanical and Dimensional Requirements

Lot Size	Sample Size	Acceptance Number	Rejection Number
25 and less	2	0	1
26 to 50	3	0	1
151 to 1 200	5	0	1
1 201 to 10 000	8	0	1
10 001 to 35 000	13	0	1
35 001 to 150 000	20	0	1
150 001 and over	32	0	1

10.5 The speed of testing as determined with a free-running cross head shall be a maximum of 0.125 in./min for the bolt proof load determination, and a maximum of 1 in./min for the bolt tensile strength determination.

11. Magnetic Particle and Visual Inspection for Surface Discontinuities

11.1 Bolts shall be examined by magnetic particle inspection for longitudinal discontinuities and transverse cracks, and shall conform to an AQL of 0.25 when inspected in accordance with the sampling plan described in 11.4. Eddy-current inspection may be substituted, at the option of the manufacturer, for the 100 % magnetic particle inspection specified in 11.4.1 and 11.4.2, provided that the bolts, after eddy current inspection, are subsequently randomly sampled according to Table 9 and subjected to the magnetic particle inspection and acceptance requirements as described above. In the case of dispute, the magnetic particle test shall govern.

11.2 Bolts shall be examined visually for bursts and shall meet an AQL of 2.5 when inspected in accordance with the sampling plan described in 11.5.

11.3 A lot, for purposes of selecting a sample for magnetic particle or visual inspection, shall consist of all bolts of one type, having the same nominal diameter and length offered for inspection at one time. No lot shall contain more than 10 000 pieces.

11.4 *Longitudinal Discontinuities and Transverse Cracks:*

11.4.1 From each lot of bolts a representative sample shall be picked at random and magnetic particle inspected for rejectable longitudinal discontinuities and transverse cracks (as described in 11.4.2) in accordance with Practice E 709. (See Note 5.) The sample size shall be as specified for an AQL of 0.25 in Table 9. If any defectives are found during inspection by the manufacturer all bolts in the lot shall be magnetic particle inspected and all defectives shall be removed and destroyed. If any defectives are found during inspection by the purchaser the lot shall be subject to rejection.

TABLE 9 Sample Sizes with Acceptance and Rejection Numbers for Inspection of Rejectable Longitudinal Discontinuities and Transverse Cracks

Lot Size	Sample Size[A, B]	Acceptance Number[A]	Rejection Number
2 to 50	all	0	1
51 to 500	50	0	1
501 to 1200	80	0	1
1201 to 3200	125	0	1
3201 to 10 000	200	0	1

[A] Sample sizes, acceptance numbers, and rejection numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105.

[B] Inspect all bolts in the lot if lot size is less than sample size.

TABLE 10 Sample Sizes with Acceptance and Rejection Numbers for Inspection of Bursts 2.5 AQL

Lot Size	Sample Size[A, B]	Acceptance Number[A]	Rejection Number
2 to 8	2	0	1
9 to 15	3	0	1
16 to 25	5	0	1
26 to 150	20	1	2
151 to 280	32	2	3
281 to 500	50	3	4
501 to 1200	80	5	6
1201 to 3200	125	7	8
3201 to 10 000	200	10	11

[A] Sample sizes, acceptance numbers, and rejection numbers are extracted from "Single Sampling Plan for Normal Inspection" Table IIA, MIL-STD-105.

[B] Inspect all bolts in the lot if the lot size is less than the sample size.

NOTE 5—Magnetic particle inspection may be conducted in accordance with Method E 138. For referee purposes Practice E 709 shall be used.

11.4.2 Any bolt with a longitudinal discontinuity (located parallel to the axis of the bolt in the threads, body, fillet, or underside of head), with a depth normal to the surface greater than 0.03*D*, where *D* is the normal bolt size in inches, shall be considered defective. In addition, any bolt with a transverse crack (located perpendicular to the axis of the bolt in the threads, body, fillet, or underside of head), shall be considered defective.

NOTE 6—Magnetic particle indications of themselves shall not be cause for rejection. If in the opinion of the inspector the indications may be cause for rejection, a representative sample shall be taken from those bolts showing indications and shall be further examined by microscopical examination to determine whether the indicated discontinuities are in accordance with the specific limits.

11.5 *Bursts:*

11.5.1 From each lot of bolts a representative sample shall be picked at random and visually inspected for bursts. The sample size shall be as specified for an AQL of 2.5 in Table 10. If the number of defectives found during inspection by the manufacturer is greater than the acceptance number given in Table 10 for the sample size, all bolts in the lot shall be visually inspected and all defectives shall be removed and destroyed. If the number of defectives found during inspection by the purchaser is greater than the acceptance number given in Table 10 for the sample size, the lot shall be subject to rejection.

11.5.2 Any bolt with a burst having a width greater than 0.010 in. plus 0.025*D*, where *D* is the nominal bolt size in inches, shall be considered defective.

12. Inspection

12.1 If the inspection described in 12.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

12.2 The inspector representing the purchaser shall have free entry to all parts of manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities, without charge, to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specification that are requested by the purchaser's representative shall be made before shipment, and shall be conducted as not to interfere unnecessarily with the operation of the works.

13. Rejection

13.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

14. Certification

14.1 When specified on the order the manufacturer shall furnish the test reports described in 9.3.7 or 9.4.6, depending on whether the bolts are furnished by the production lot or shipping lot method.

15. Responsibility

15.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser and certifies that the fastener was manufactured, sampled, tested and inspected in accordance with this specification and meets all of its requirements.

16. Product Marking

16.1 Bolt heads shall be marked A 490, and shall also be marked to identify the manufacturer. Markings may be either raised or depressed, at the option of the manufacturer.

16.2 In addition to the markings required in 16.1, Type 2 bolts shall be marked with six radial lines 30° apart.

16.3 In addition to the markings required in 16.1, Type 3 bolts shall have the A 490 underlined, and the manufacturer may add other distinguishing marks indicating that the bolt is atmospheric corrosion resistant and of a weathering type.

17. Packaging and Package Marking

17.1 *Packaging:*

17.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

17.1.2 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

17.2 *Package Marking:*

17.2.1 Each shipping unit shall include or be plainly marked with the following information:

17.2.1.1 ASTM designation and type,

17.2.1.2 Size,

17.2.1.3 Name and brand or trademark of the manufacturer,

17.2.1.4 Number of pieces,

17.2.1.5 Lot number,

17.2.1.6 Purchase order number, and

17.2.1.7 Country of origin.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this specification that have been incorporated since the last issue. For the convenience of the user, Committee F 16 has highlighted those changes that may impact the use of this specification. This section may also include descriptions of the changes or reasons for the changes, or both.

(1) Added 17.1, Packaging, in accordance with Practice D 3951 and 17.2, Package Marking.

Designation: A 563 – 90

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for Carbon and Alloy Steel Nuts[1]

This standard is issued under the fixed designation A 563; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers chemical and mechanical requirements for eight grades of carbon and alloy steel nuts for general structural and mechanical uses on bolts, studs, and other externally threaded parts.

NOTE 1—See Appendix X1 for guidance on suitable application of nut grades.

1.2 The requirements for any grade of nut may, at the supplier's option, and with notice to the purchaser, be fulfilled by furnishing nuts of one of the stronger grades specified herein unless such substitution is barred in the inquiry and purchase order.

1.3 Grades C3 and DH3 nuts have atmospheric corrosion resistance and weathering characteristics comparable to that of the steels covered in Specifications A 242/A 242M, A 588/A 588M, and A 709 (these steels have atmospheric corrosion resistance approximately two times that of carbon structural steel with copper).

NOTE 2—A complete metric companion to Specification A 563 has been developed—A 563M; therefore, no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[2]

A 194/A 194M Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service[3]

A 242/A 242M Specification for High-Strength Low-Alloy Structural Steel[4]

A 307 Specification for Carbon Steel Bolts and Studs, 60 000 psi Tensile Strength[3]

A 325 Specification for High-Strength Bolts for Structural Steel Joints[5]

A 354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners[3]

A 394 Specification for Zinc-Coated Steel Transmission Tower Bolts[5]

A 449 Specification for Quenched and Tempered Steel Bolts and Studs[5]

A 490 Specification for Heat-Treated, Steel Structural Bolts, 150 ksi (1035 MPa) Tensile Strength[5]

A 588/A 588M Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4 in. (100 mm) Thick[4]

A 687 Specification for High-Strength Nonheaded Steel Bolts and Studs[5]

A 709 Specification for Structural Steel for Bridges[4]

A 751 Methods, Practices, and Definitions for Chemical Analysis of Steel Products[6]

B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel[7]

D 3951 Practice for Commercial Packaging[8]

F 606 Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets[5]

2.2 *ANSI Standards:*

ANSI B1.1 Unified Screw Threads[9]

ANSI B18.2.2 Square and Hex Nuts[9]

3. Ordering Information

3.1 Orders for nuts under this specification shall include the following:

3.1.1 Quantity (number of nuts),

3.1.2 Nominal size and thread series of nuts,

3.1.3 Style of nut (for example, heavy hex),

3.1.4 Grade of nut,

3.1.5 *Zinc Coating*—Specify the zinc-coating process required, for example, hot-dip, mechanically deposited, or no preference (see 4.7),

3.1.6 *Other Finishes*—Specify other protective finish if required,

3.1.7 ASTM designation and year of issue, and

3.1.8 Supplementary or special requirements.

NOTE 3—An example of an ordering description follows: 1000 ⅞-9 heavy hex nuts, Grade DH, hot-dip zinc-coated, and lubricated, ASTM A 563–XX.

4. Manufacturing Processes

4.1 Steel for nuts shall be made by the open-hearth, basic-oxygen, or electric-furnace process except that steel for Grades O, A, and B nuts may be made by the acid-bessemer process.

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[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets, and Washers.

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[2] *Annual Book of ASTM Standards*, Vol 01.06.

[3] *Annual Book of ASTM Standards*, Vols 01.01 and 15.08.

[4] *Annual Book of ASTM Standards*, Vol 01.04.

[5] *Annual Book of ASTM Standards*, Vol 15.08.

[6] *Annual Book of ASTM Standards*, Vols 01.01, 01.02, 01.03, 01.04, 01.05, and 03.05.

[7] *Annual Book of ASTM Standards*, Vol 02.05.

[8] *Annual Book of ASTM Standards*, Vol 15.09.

[9] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

* A Summary of Changes section appears at the end of this specification.

4.2 Nuts may be made cold or hot by forming, pressing, or punching or may be machined from bar stock.

4.3 Grades DH and DH3 nuts shall be heat treated by quenching in a liquid medium from a temperature above the transformation temperature and tempering at a temperature of at least 800°F.

4.4 Grades C and D nuts made of steel having carbon content not exceeding 0.20 %, phosphorus not exceeding 0.04 %, and sulfur not exceeding 0.05 % by heat analysis may be heat treated by quenching in a liquid medium from a temperature above the transformation temperature and need not be tempered. When this heat treatment is used, there shall be particular attention to the requirements in 6.1.

4.5 Grades C, C3, and D nuts made of any steel permitted for these grades may be heat treated by quenching in a liquid medium from a temperature above the transformation temperature and tempering at a temperature of at least 800°F.

4.6 Threads shall be formed by tapping or machining.

4.7 *Zinc Coatings, Hot-Dip and Mechanically Deposited:*

4.7.1 When zinc-coated fasteners are required, the purchaser shall specify the zinc coating process, for example, hot-dip, mechanically deposited, or no preference.

4.7.2 When hot-dip is specified, the fasteners shall be zinc-coated by the hot-dip process in accordance with the requirements of Class C, of Specification A 153.

4.7.3 When mechanically deposited is specified, the fasteners shall be zinc coated by the mechanical deposition process in accordance with the requirements of Class 50 of Specification B 695.

4.7.4 When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with Specification A 153, Class C, or a mechanically deposited zinc coating in accordance with Specification B 695, Class 50. All components of mating fasteners (bolts, nuts, and washers) shall be coated by the same zinc-coating process and the supplier's option is limited to one process per item with no mixed processes in a lot.

4.7.5 Hot-dip zinc-coated nuts shall be tapped after zinc coating.

4.7.6 Mechanically deposited zinc-coated nuts for assembly with mechanically deposited zinc-coated bolts shall be tapped oversize prior to zinc coating and need not be retapped afterwards.

4.8 Hot-dip and mechanically deposited zinc-coated Grade DH nuts shall be provided with an additional lubricant which shall be clean and dry to the touch.

5. Chemical Composition

5.1 Steel for nuts of Grades O, A, B, C, D, and DH shall conform in chemical composition to the limits listed in Table 1.

5.2 Steel for nuts of Grades C3 and DH3 shall conform in chemical composition to the limits listed in Table 2.

5.3 Resulfurized steel is not subject to rejection based on product analysis for sulfur. Rephosphorized steel is not subject to rejection based on product analysis for phosphorus.

5.4 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for Grades D, DH, and DH3.

5.5 Chemical analyses shall be performed in accordance with Methods, Practices, and Definitions A 751.

TABLE 1 Chemical Requirements for Grades O, A, B, C, D, and DH Nuts

Grade of Nut	Composition, %				
	Analysis	Carbon	Manganese, min	Phosphorus, max	Sulfur, max
O, A, B, C	heat	0.55 max	...	0.12	0.15[A]
	product	0.58 max	...	0.13[B]	...
D[C]	heat	0.55 max	0.30	0.04	0.05
	product	0.58 max	0.27	0.048	0.058
DH[C]	heat	0.20–0.55	0.60	0.04	0.05
	product	0.18–0.58	0.57	0.048	0.058

[A] Sulfur content may be 0.23 max for Grade O, A, and B nuts if agreed between the manufacturer and the purchaser.

[B] Acid bessemer steel only.

[C] For D and DH nuts, sulfur content may be 0.05 to 0.15 % in which case manganese must be a minimum of 1.35 %.

6. Mechanical Properties

6.1 The hardness of nuts of each grade shall not exceed the maximum hardness specified for the grade in Table 3.

6.2 Jam nuts, slotted nuts, nuts smaller in width across flats or thickness than standard hex nuts (7.1), and nuts that would require a proof load in excess of 160 000 lbf may be furnished on the basis of minimum hardness requirements specified for the grade in Table 3, unless proof load testing is specified in the inquiry and purchase order.

6.3 Nuts of each grade, except those listed in 6.2, shall withstand the proof load stress specified for the grade, size, style, thread series, and surface finish of the nut in Table 3.

6.4 The speed of testing as determined with a free-running cross head shall be a maximum of 1 in./min for nut proof load determination.

7. Dimensions

7.1 Unless otherwise specified, nuts shall be plain (uncoated) and shall conform to the dimensions prescribed in ANSI B18.2.2.

7.2 Hex and hex-slotted nuts over 1½ to 2 in. inclusive shall have dimensions conforming to ANSI B18.2.2 calculated using the formulas for the 1¼ through 1½-in. size range in Appendix III (Formulas for Nut Dimensions) of ANSI B18.2.2.

7.3 Unless otherwise specified, the thread in nuts shall conform to the dimensions for coarse thread with Class 2 B tolerances prescribed in ANSI B1.1.

7.4 Nuts to be used on bolts threaded with Class 2 A threads before hot-dip zinc coating, and then hot-dip zinc-coated in accordance with Specification A 153, Class C, shall be tapped oversize at least by the following minimum diametral amounts:

Diameter, in.	in.[A]
7/16 and smaller	0.016
Over 7/16 to 1	0.021
Over 1	0.031

[A] Applies to both pitch and minor diameters, minimum and maximum limits.

7.5 Nuts to be used on bolts mechanically zinc coated or on bolts hot-dip zinc-coated to a specification other than Specification A 153, Class C, or otherwise hot-dip coated, shall be tapped oversize by a diametral amount sufficient to permit assembly on the coated bolt thread, unless other requirements are specified in the inquiry or purchase order.

7.6 When specifically permitted by the purchaser, nuts for bolts with electrodeposited coating, such as cadmium, zinc, etc., or with chemically applied coating may be tapped oversize by a diametral amount sufficient to permit assembly on the coated bolt thread.

8. Number of Tests

8.1 The requirements of this specification shall be met in continuous mass production for stock, and the manufacturer shall make sample inspections to ensure that the product conforms to the specified requirements (Section 14). Additional tests of individual shipments of material are not ordinarily contemplated. Individual heats of steel are not identified in the finished product.

8.2 When additional tests are specified in the inquiry and purchase order, a lot, for purposes of selecting test samples, shall consist of all material offered for inspection at one time that has the following common characteristics:

8.2.1 Grade,

8.2.2 Nominal size,

8.2.3 Style of nut,

8.2.4 Thread series and class, and

8.2.5 Surface finish.

8.3 Unless otherwise specified in the inquiry and purchase order, the number of tests for each lot of required property shall be as follows:

Number of Nuts in Lot	Number of Specimens
800 and under	1
801 to 8 000	2
8 001 to 22 000	3
Over 22 000	5

8.4 If any test specimen shows flaws, it may be discarded and another specimen substituted.

8.5 Should any specimen fail to meet the requirements of any specified test, double the number of specimens from the same lot shall be tested for this property, in which case all of the additional specimens shall meet the specifications.

9. Test Methods

9.1 Tests shall be conducted in accordance with Test Methods F 606.

10. Inspection

10.1 If the inspection described in 10.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

10.2 The inspector representing the purchaser shall have free entry to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specification that are requested by the purchaser's repre-

TABLE 2 Chemical Requirements for Grades C3 and DH3 Nuts

Element	Composition, %							
	Classes for Grade C3 Nuts[A]							Grade DH3 Nuts
	N	A	B	C	D	E	F	
Carbon:								
Heat analysis	...	0.33–0.40	0.38–0.48	0.15–0.25	0.15–0.25	0.20–0.25	0.20–0.25	0.20–0.53
Product analysis	...	0.31–0.42	0.36–0.50	0.14–0.26	0.14–0.26	0.18–0.27	0.19–0.26	0.19–0.55
Manganese:								
Heat analysis	...	0.90–1.20	0.70–0.90	0.80–1.35	0.40–1.20	0.60–1.00	0.90–1.20	0.40 min
Product analysis	...	0.86–1.24	0.67–0.93	0.76–1.39	0.36–1.24	0.56–1.04	0.86–1.24	0.37 min
Phosphorus:								
Heat analysis	0.07–0.15	0.040 max	0.06–0.12	0.035 max	0.040 max	0.040 max	0.040 max	0.046 max
Product analysis	0.07–0.155	0.045 max	0.06–0.125	0.040 max	0.045 max	0.045 max	0.045 max	0.052 max
Sulfur:								
Heat analysis	0.050 max	0.050 max	0.050 max	0.040 max	0.050 max	0.040 max	0.040 max	0.050 max
Product analysis	0.055 max	0.055 max	0.055 max	0.045 max	0.055 max	0.045 max	0.045 max	0.055 max
Silicon:								
Heat analysis	0.20–0.90	0.15–0.35	0.30–0.50	0.15–0.35	0.25–0.50	0.15–0.35	0.15–0.35	...
Product analysis	0.15–0.95	0.13–0.37	0.25–0.55	0.13–0.37	0.20–0.55	0.13–0.37	0.13–0.37	...
Copper:								
Heat analysis	0.25–0.55	0.25–0.45	0.20–0.40	0.20–0.50	0.30–0.50	0.30–0.60	0.20–0.40	0.20 min
Product analysis	0.22–0.58	0.22–0.48	0.17–0.43	0.17–0.53	0.27–0.53	0.27–0.63	0.17–0.43	0.17 min
Nickel:								
Heat analysis	1.00 max	0.25–0.45	0.50–0.80	0.25–0.50	0.50–0.80	0.30–0.60	0.20–0.40	0.20 min[B]
Product analysis	1.03 max	0.22–0.48	0.47–0.83	0.22–0.53	0.47–0.83	0.27–0.63	0.17–0.43	0.17 min
Chromium:								
Heat analysis	0.30–1.25	0.45–0.65	0.50–0.75	0.30–0.50	0.50–1.00	0.60–0.90	0.45–0.65	0.45 min
Product analysis	0.25–1.30	0.42–0.68	0.47–0.83	0.27–0.53	0.45–1.05	0.55–0.95	0.42–0.68	0.42 min
Vanadium:								
Heat analysis	...	...	...	0.020 min	...	...	...	...
Product analysis	...	...	...	0.010 min	...	...	...	...
Molybdenum:								
Heat analysis	...	...	0.06 max	...	0.10 max	...	...	0.15 min[B]
Product analysis	...	...	0.07 max	...	0.11 max	...	...	0.14 min
Titanium:								
Heat analysis	...	...	...	...	0.05 max	...	...	...
Product analysis	...	...	...	...	...	...	...	...

[A] C3 nuts may be made of any of the above listed material classes. Selection of the class shall be at the option of the manufacturer.

[B] Nickel or molybdenum may be used.

TABLE 3 Mechanical Requirements
Nuts with UNC, 8 UN, 6 UN and Coarser Pitch Threads

Grade of Nut	Nominal Nut Size, in.	Style of Nut	Proof Load Stress, ksi[A] Non-Zinc-Coated Nuts[B]	Proof Load Stress, ksi[A] Zinc-Coated Nuts[B]	Hardness Brinell min	Hardness Brinell max	Hardness Rockwell min	Hardness Rockwell max
O	1/4 to 1 1/2	square	69	52	103	302	B55	C32
A	1/4 to 1 1/2	square	90	68	116	302	B68	C32
O	1/4 to 1 1/2	hex	69	52	103	302	B55	C32
A	1/4 to 1 1/2	hex	90	68	116	302	B68	C32
B	1/4 to 1	hex	120	90	121	302	B69	C32
B	1 1/8 to 1 1/2	hex	105	79	121	302	B69	C32
D[C]	1/4 to 1 1/2	hex	135	135	159	352	B84	C38
DH[D]	1/4 to 1 1/2	hex	150	150	248	352	C24	C38
DH3	1/2 to 1	hex	150	150	248	352	C24	C38
A	1/4 to 4	heavy hex	100	75	116	302	B68	C32
B	1/4 to 1	heavy hex	133	100	121	302	B69	C32
B	1 1/8 to 1 1/2	heavy hex	116	87	121	302	B69	C32
C[C]	1/4 to 4	heavy hex	144	144	143	352	B78	C38
C3	1/4 to 4	heavy hex	144	144	143	352	B78	C38
D[C]	1/4 to 4	heavy hex	150	150	159	352	B84	C38
DH[D]	1/4 to 4	heavy hex	175	175	248	352	C24	C38
DH3	1/4 to 4	heavy hex	175	175	248	352	C24	C38
A	1/4 to 1 1/2	hex thick	100	75	116	302	B68	C32
B	1/4 to 1	hex thick	133	100	121	302	B69	C32
B	1 1/8 to 1 1/2	hex thick	116	87	121	302	B69	C32
D[C]	1/4 to 1 1/2	hex thick	150	150	159	352	B84	C38
DH[D]	1/4 to 1 1/2	hex thick	175	175	248	352	C24	C38
Nuts with UNF, 12 UN, and Finer Pitch Threads								
O	1/4 to 1 1/2	hex	65	49	103	302	B55	C32
A	1/4 to 1 1/2	hex	80	60	116	302	B68	C32
B	1/4 to 1	hex	109	82	121	302	B69	C32
B	1 1/8 to 1 1/2	hex	94	70	121	302	B69	C32
D[C]	1/4 to 1 1/2	hex	135	135	159	352	B84	C38
DH[D]	1/4 to 1 1/2	hex	150	150	248	352	C24	C38
A	1/4 to 4	heavy hex	90	68	116	302	B68	C32
B	1/4 to 1	heavy hex	120	90	121	302	B69	C32
B	1 1/8 to 1 1/2	heavy hex	105	79	121	302	B69	C32
D[C]	1/4 to 4	heavy hex	150	150	159	352	B84	C38
DH[D]	1/4 to 4	heavy hex	175	175	248	352	C24	C38
A	1/4 to 1 1/2	hex thick	90	68	116	302	B68	C32
B	1/4 to 1	hex thick	120	90	121	302	B69	C32
B	1 1/8 to 1 1/2	hex thick	105	79	121	302	B69	C32
D[C]	1/4 to 1 1/2	hex thick	150	150	159	352	B84	C38
DH[D]	1/4 to 1 1/2	hex thick	175	175	248	352	C24	C38

[A] To determine nut proof load in pounds, multiply the appropriate nut proof load stress by the tensile stress area of the thread. Stress areas for UNC, UNF, and 8 UN thread series are given in Table 4.

[B] Non-zinc-coated nuts are nuts intended for use with externally threaded fasteners which have a plain (nonplated or noncoated) finish or have a plating or coating of insufficient thickness to necessitate overtapping the nut thread to provide assemblability. Zinc-coated nuts are nuts intended for use with externally threaded fasteners which are hot-dip zinc-coated, mechanically zinc-coated, or have a plating or coating of sufficient thickness to necessitate overtapping the nut thread to provide assemblability.

[C] Nuts made in accordance to the requirements of Specification A 194/A 194M, Grade 2 or Grade 2H, and marked with their grade symbol are acceptable equivalents for Grades C and D nuts.

[D] Nuts made in accordance with the requirements of Specification A 194/A 194M, Grade 2H, and marked with its grade symbol are an acceptable equivalent for Grade DH nuts.

sentative shall be made before shipment, and shall be conducted as not to interfere unnecessarily with the operation of the works.

11. Rejection

11.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

12. Product Marking

12.1 Nuts made to the requirements of Grades O, A, and B are not required to be marked unless individual marking is specified in the inquiry and order. When individual marking is required, the mark shall be the grade letter symbol on one face of the nut.

12.2 Heavy hex nuts made to the requirements of Grade C (Note 4) shall be marked on one face with three circumferential marks 120° apart.

12.3 Heavy hex nuts made to the requirements of Grade C3 shall be marked on one face with three circumferential marks 120° apart and the numeral 3. In addition, the manufacturer may add other distinguishing marks indicating that the nut is atmospheric corrosion resistant and of a weathering type.

TABLE 4 Tensile Stress Areas

Nominal Size–Threads per Inch	UNC Tensile Stress Area,[A] in.²	Nominal Size–Threads per Inch	UNF Tensile Stress Area,[A] in.²	Nominal Size–Threads per Inch	8 UN Tensile Stress Area,[A] in.²
1/4–20	0.0318	1/4–28	0.0364	...	...
5/16–18	0.0524	5/16–24	0.0580	...	...
3/8–16	0.0775	3/8–24	0.0878	...	...
7/16–14	0.1063	7/16–20	0.1187	...	...
1/2–13	0.1419	1/2–20	0.1599	...	...
9/16–12	0.182	9/16–18	0.203	...	...
5/8–11	0.226	5/8–18	0.256	...	...
3/4–10	0.334	3/4–16	0.373	...	...
7/8–9	0.462	7/8–14	0.509	...	...
1–8	0.606	1–12	0.663	1–8	0.606
1 1/8–7	0.763	1 1/8–12	0.856	1 1/8–8	0.790
1 1/4–7	0.969	1 1/4–12	1.073	1 1/4–8	1.000
1 3/8–6	1.155	1 3/8–12	1.315	1 3/8–8	1.233
1 1/2–6	1.405	1 1/2–12	1.581	1 1/2–8	1.492
1 3/4–5	1.90	...	...	1 3/4–8	2.08
2–4 1/2	2.50	...	...	2–8	2.77
2 1/4–4 1/2	3.25	...	...	2 1/4–8	3.56
2 1/2–4	4.00	...	...	2 1/2–8	4.44
2 3/4–4	4.93	...	...	2 3/4–8	5.43
3–4	5.97	...	...	3–8	6.51
3 1/4–4	7.10	...	...	3 1/4–8	7.69
3 1/2–4	8.33	...	...	3 1/2–8	8.96
3 3/4–4	9.66	...	...	3 3/4–8	10.34
4–4	11.08	...	...	4–8	11.81

[A] The stress area is calculated as follows:

$$A_s = 0.7854\left[D - \frac{0.9743}{n}\right]^2$$

where:
A_s = stress area, in.²,
D = nominal size, in., and
n = threads per inch.

12.4 Nuts made to the requirements of Grade D shall be marked with the grade symbol, D (Note 4) on one face.

12.5 Nuts made to the requirements of Grade DH shall be marked with the grade symbol, DH (Note 4) on one face.

12.6 Heavy hex nuts made to the requirements of Grade DH3 shall be marked with the grade symbol DH3 on one face. Hex nuts made to the requirements of DH3 shall be marked with the symbol HX3 on one face. In addition, the manufacturer may add other distinguishing marks indicating that the nut is atmospheric corrosion resistant and of a weathering type.

12.7 In addition, nuts of Grades C, C3, D, DH, and DH3 and hex nuts made to the requirements of DH3, shall be marked with a symbol to identify the manufacturer.

12.8 Marks may be raised or depressed at the option of the manufacturer. However, if markings are located on the bearing surface, they shall be depressed.

NOTE 4—See Table 3 for marking of equivalent nuts made in accordance with requirements of Specification A 194/A 194M.

13. Packaging and Package Marking

13.1 *Packaging:*

13.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

13.1.2 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

13.2 *Package Marking:*

13.2.1 Each shipping unit shall include or be plainly marked with the following information:

13.2.1.1 ASTM designation and grade,

13.2.1.2 Size,

13.2.1.3 Name and brand or trademark of the manufacturer,

13.2.1.4 Number of pieces,

13.2.1.5 Purchase order number, and

13.2.1.6 Country of origin.

14. Report

14.1 When specified in the order, the manufacturer shall furnish a test report certified to be the last completed set of mechanical tests for each stock size in each shipment.

15. Responsibility

15.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser and certifies that the fastener was manufactured, sampled, tested and inspected in accordance with the specification and meets all of its requirements.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall be applied only when specified by the purchaser on the contract or order. Details of these supplementary requirements shall be agreed upon in writing between the manufacturer and purchaser. This supplementary requirement shall in no way negate any requirement of the specification itself.

S1. Lubricant and Test for Coated Nuts

S1.1 Nuts shall be provided with an additional lubricant that shall be clean and dry to the touch.

S1.2 Galvanized bolts and galvanized and lubricated nuts shall be capable of conforming to the test requirement in S1.2.1. After this tightening test, the assembly shall show no signs of failure.

TABLE S1.1 Tightening Test For Coated Nuts

Bolt Length, in.	Nominal Nut Rotation, Deg (turn)
Up to and including 4 × dia	300 (5/6)
Over 4 × dia but not exceeding 8 × dia	360 (1)
Over 8 × dia	420 (1 1/6)

S1.2.1 A galvanized bolt shall be placed in a steel joint and assembled with a galvanized washer and a galvanized nut. The joint shall be one or more flat structural steel plates with a total thickness, including the washer, such that 3 to 5 full threads of the bolt are located between the bearing surfaces of the bolt head and nut. The hole in the joint shall have the same nominal diameter as the hole in the washer. The initial tightening of the nut shall produce a load in the bolt not less than 10 % of the specified proof load. After this initial tightening, the nut position shall be marked relative to the bolt and the rotation shown in Table S1.1 shall be applied. During rotation the bolt head shall be restrained from turning.

APPENDIX

(Nonmandatory Information)

X1. INTENDED APPLICATION

X1.1 Table X1.1 gives additional information for the intended application of nuts.

TABLE X1.1 Nut and Bolt Suitability Guide

Grade of Bolt[D]	Surface Finish[E]	Nominal Size, in.	A563 Grade and ANSI Nut Style[A]					
			Recommended[B]		Suitable[C]			
			Hex	Heavy Hex	Square	Hex	Heavy Hex	Hex Thick
A 307 Grade A	non-zinc-coated and zinc-coated	¼ to 1½	A	...	A	B,D,DH	A,B,C,D,DH,DH3	A,B,D,DH
		>1½ to 2	...	A	...	A[F]	C,D,DH,DH3	...
		>2 to 4	...	A	...	...	C,D,DH,DH3	...
A 307 Grade B	non-zinc-coated and zinc-coated	¼ to 1½	...	A	A	B,D,DH	B,C,D,DH,DH3	A,B,D,DH
		>1½ to 2	...	A	...	A[F]	C,D,DH,DH3	...
		>2 to 4	...	A	...	...	C,D,DH,DH3	...
A 325 Types 1 and 2	non-zinc-coated	½ to 1½	...	C	...	...	C3,D,DH,DH3	...
	zinc-coated	½ to 1½	...	DH	...	...	...	...
A 325 Type 3	non-zinc-coated	½ to 1½	...	C3	...	...	DH3	...
A 354 Grade BC	non-zinc-coated	¼ to 1½	...	C	...	D,DH	C3,D,DH,DH3	D,DH
		>1½ to 4	...	C	...	...	C3,D,DH,DH3	...
	zinc-coated	¼ to 1½	...	DH	...	...	...	DH
		>1½ to 4	...	DH	...	...	...	...
A 354 Grade BD	non-zinc-coated	¼ to 1½	...	DH	...	DH	D,DH,DH3	D,DH
		>1½ to 4	...	DH	...	...	DH3	...
A 394 Type 0	zinc-coated	½ to 1	A	...	...	B,D	...	...
A 394 Type 1 and 2	zinc-coated	½ to 1	DH	...	...	D	...	...
A 394 Type 3	non-zinc-coated	½ to 1	DH3	...	...	...	C3	...
A 449 Types 1 and 2	non-zinc-coated	¼ to 1½	B	...	...	D,DH	B,C,C3,D,DH,DH3	B,D,DH
		>1½ to 3	...	A	...	...	C,C3,D,DH,DH3	...
	zinc-coated	¼ to 1½	...	DH	...	D,DH	D	D,DH
		>1½ to 3	...	DH	...	...	D	...
A 490 Type 1	non-zinc-coated	½ to 1½	...	DH	...	...	DH3	...
A 490 Type 3	non-zinc-coated	½ to 1½	...	DH3	...	...	...	...
A 687	non-zinc-coated	1¼ to 3	...	D	...	...	DH,DH3	...
	zinc-coated	1¼ to 3	...	DH	...	...	...	...

[A] The availability of DH nuts in nominal sizes ¾ in. and larger is very limited and generally available only on special orders for 50 000 pieces or more. For smaller quantities A194 Gr. 2H nuts should be considered.

[B] "Recommended" denotes a commercially available nut having the most suitable mechanical properties and dimensional configuration (style) that will make it possible to torque the bolt to the required load when used in combination with the nut.

[C] "Suitable" denotes nuts having mechanical properties that will make it possible to torque the bolt to the required load when used in combination with the nut; but, which require consideration of dimensional configuration (style) suitability and availability. Others are not suitable.

[D] The term "bolt" includes all externally threaded types of fasteners.

[E] Non-zinc-coated nuts are nuts intended for use with externally threaded fasteners which have a plain (nonplated or noncoated) finish or have a plating or coating of insufficient thickness to necessitate overtapping the nut thread to provide assemblability. Zinc-coated nuts are nuts intended for use with externally threaded fasteners which are hot-dip zinc-coated, mechanically zinc-coated, or have a plating or coating of sufficient thickness to necessitate overtapping the nut thread to provide assemblability.

[F] Hex nuts in nominal sizes over 1½ to 2 in. inclusive are not covered in the tables of tabulated sizes in ANSI B18.2.2 but are commercially available. Such nuts are suitable. See 7.2 for dimensions.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this specification that have been incorporated since the last issue. For the convenience of the user, Committee F 16 has highlighted those changes that may impact the use of this specification. This section may also include descriptions of the changes or reasons for the changes, or both.

(1) Added 13.1 Packaging in accordance with Practice D 3951 and 13.2 Package Marking.

(2) In Supplementary Requirements Table S1.1 corrected the bolt length to be a function of the diameter.

(3) Realigned Table X1.1 to improve readability, revised definition of "recommended" and "suitable," and deleted Grade C Heavy Hex zinc-coated nuts as recommended for Specification A 449.

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Standard Specification for Hardened Steel Washers[1]

This standard is issued under the fixed designation F 436; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers the chemical, mechanical, and dimensional requirements for hardened steel washers for use with fasteners having nominal thread diameters of ¼ through 4 in. These washers are intended for general-purpose mechanical and structural use with bolts, nuts, studs, and other internally and externally threaded fasteners. These washers are suitable for use with fasteners covered in specifications A 325, A 354, A 449, A 490, and A 687.

1.2 The washers are designated by *type* denoting the material and by *style* denoting the shape.

1.2.1 The types of washers covered are:

1.2.1.1 *Type 1*—Carbon steel.

1.2.1.2 *Type 3*—Weathering steel. Atmospheric corrosion resistance and weathering characteristics are comparable to that of steels covered in Specifications A 588/A 588M and A 709, that is two times that of carbon structural steel with copper.

1.2.2 The styles of washers covered are:

1.2.2.1 *circular*—Circular washers in nominal bolt sizes ¼ through 4 in. suitable for applications where sufficient space exists and angularity permits.

1.2.2.2 *beveled*—Beveled washers are square or rectangular, in nominal sizes ½ through 1 ½ in., with a beveled 1 to 6 ratio surface for use with American standard beams and channels.

1.2.2.3 *clipped*—Clipped washers are circular or beveled for use where space limitations necessitate that one side be clipped.

NOTE—A complete metric companion to Specification F 436 has been developed—Specification F 436M; therefore no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware[2]

A 325 Specification for High-Strength Bolts for Structural Steel Joints[3]

A 354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners[3]

A 449 Specification for Quenched and Tempered Steel Bolts and Studs[3]

A 490 Specification for Heat-Treated, Steel Structural Bolts, 150 ksi (1035 MPa) Tensile Strength[3]

A 588/A 588M Specification for High-Strength Low-Alloy Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4 in. [100 mm] Thick[4]

A 687 Specification for High-Strength Nonheaded Steel Bolts and Studs[3]

A 709 Specification for Structural Steel for Bridges[4]

A 751 Methods, Practices, and Definitions for Chemical Analysis of Steel Products[5]

B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel[6]

D 3951 Practice for Commercial Packaging[7]

F 606 Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets[3]

3. Ordering Information

3.1 Orders for hardened steel washers under this specification shall include the following:

3.1.1 ASTM designation and year of issue,

3.1.2 Quantity (number of pieces by size),

3.1.3 Type and Style (see 1.2.1 and 1.2.2),

3.1.4 *Zinc Coating*—Specify the zinc coating process required, for example, hot-dip, mechanically deposited, or no preference (see 4.3),

3.1.5 Dimensions, nominal size, and other dimensions, if modified from those covered in this specification,

3.1.6 Specify if inspection at point of manufacture is required,

3.1.7 Specify if manufacturer's certification or test reports, or both, are required, and

3.1.8 Special requirements.

4. Materials and Manufacture

4.1 Steel used in the manufacture of washers shall be produced by the open-hearth, basic-oxygen, or electric-furnace process.

4.2 Washers up to and including 1½ in. in bolt size shall

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets, and Washers.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as F 436 – 76. Last previous edition F 436 – 89.

[2] *Annual Book of ASTM Standards*, Vols 01.06 and 15.08.

[3] *Annual Book of ASTM Standards*, Vol 15.08.

[4] *Annual Book of ASTM Standards*, Vol 01.04.

[5] *Annual Book of ASTM Standards*, Vol 01.03.

[6] *Annual Book of ASTM Standards*, Vols 02.05 and 15.08.

[7] *Annual Book of ASTM Standards*, Vol. 15.09.

*** A Summary of Changes section appears at the end of this specification.**

TABLE 1 Chemical Requirements

Element	Composition, %	
	Type 1	Type 3[A]
Phosphorus, max		
Heat analysis	0.040	0.040
Product analysis	0.050	0.045
Sulfur, max		
Heat analysis	0.050	0.050
Product analysis	0.060	0.055
Silicon		
Heat analysis	...	0.15–0.35
Product analysis	...	0.13–0.37
Chromium		
Heat analysis	...	0.45–0.65
Product analysis	...	0.42–0.68
Nickel		
Heat analysis	...	0.25–0.45
Product analysis	...	0.22–0.48
Copper		
Heat analysis	...	0.25–0.45
Product analysis	...	0.22–0.48

[A] Weathering steel washers may also be manufactured from any of the steels listed in Table 2 of Specification A 325.

be through hardened. Washers over 1½ in. may be either through hardened or carburized at the option of the manufacturer.

4.3 *Zinc Coatings, Hot-Dip and Mechanically Deposited:*

4.3.1 When zinc-coated washers are required, the purchaser shall specify the zinc coating process, for example, hot-dip, mechanically deposited, or no preference.

4.3.2 When hot-dip is specified the washers shall be zinc coated by the hot-dip process in accordance with the requirements of Class C of Specification A 153.

4.3.3 When mechanically deposited is specified the washers shall be zinc coated by the mechanical-deposition process in accordance with the requirements of Class 50 of Specification B 695.

4.3.4 When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with Specification A 153, Class C, or a mechanically deposited zinc coating in accordance with Specification B 695, Class 50, all components of mating fasteners (bolts, nuts, and washers) shall be coated by the same zinc-coating process and the supplier's option is limited to one process per item with no mixed processes in a lot.

4.4 If washers are heat treated by a subcontractor, they shall be returned to the manufacturer for testing prior to shipment to the purchaser.

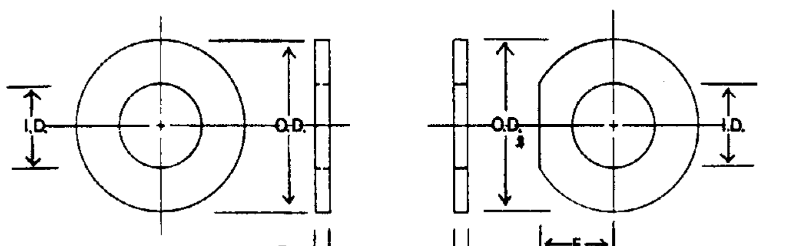
5. Chemical Composition

5.1 All washers shall conform to the requirements as to chemical composition prescribed in Table 1.

5.2 Product analysis may be made by the purchaser from

TABLE 2 Hardened Circular and Clipped Circular Washers

NOTE 1—Tolerances are as noted in table on washer dimension tolerances.



Circular   Clipped Circular

Bolt Size	Circular and Clipped Circular				Clipped
	Nominal Outside Diameter (OD), in.	Nominal Inside Diameter (ID), in.	Thickness (*T*), in.		Minimum Edge Distance (*E*)[A], in.
			min	max	
¼	⅝	9/32	0.051	0.080	7/32
5/16	11/16	11/32	0.051	0.080	9/32
⅜	13/16	13/32	0.051	0.080	11/32
7/16	59/64	15/32	0.051	0.080	13/32
½	1 1/16	17/32	0.097	0.177	7/16
⅝	1 5/16	11/16	0.122	0.177	9/16
¾	1 15/32	13/16	0.122	0.177	21/32
⅞	1¾	15/16	0.136	0.177	25/32
1	2	1⅛	0.136	0.177	⅞
1⅛	2¼	1¼	0.136	0.177	1
1¼	2½	1⅜	0.136	0.177	1 3/32
1⅜	2¾	1½	0.136	0.177	1 7/32
1½	3	1⅝	0.136	0.177	1 5/16
1¾	3⅜	1⅞	0.178[B]	0.28[B]	1 17/32
2	3¾	2⅛	0.178[B]	0.28[B]	1¾
2¼	4	2⅜	0.24[C]	0.34[C]	2
2½	4½	2⅝	0.24[C]	0.34[C]	2 3/16
2¾	5	2⅞	0.24[C]	0.34[C]	2 13/32
3	5½	3⅛	0.24[C]	0.34[C]	2⅝
3¼	6	3⅜	0.24[C]	0.34[C]	2⅞
3½	6½	3⅝	0.24[C]	0.34[C]	3 1/16
3¾	7	3⅞	0.24[C]	0.34[C]	3 5/16
4	7½	4⅛	0.24[C]	0.34[C]	3½

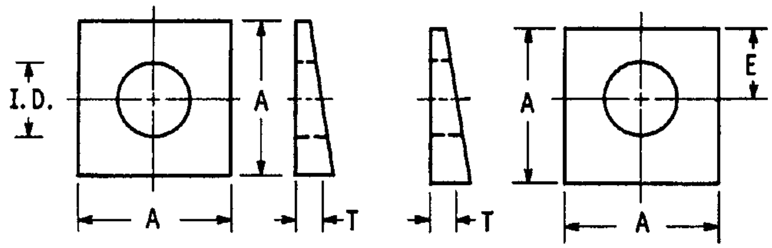
[A] Clipped edge *E* shall be not closer than ⅞ of the bolt diameter from the center of the washer.

[B] 3/16 in. nominal.

[C] ¼ in. nominal.

TABLE 3 Hardened Beveled Washers

NOTE 1—Tolerances are as noted in Table 4.



Square   Square Clipped

Bolt Size, in.	Square Beveled and Clipped Square Beveled[A]				Clipped
	Minimum Side Dimension *(A)*, in.	Nominal Inside Diameter (I.D.), in.	Mean Thickness *(T)*, in.	Slope or Taper in Thickness	Nominal Edge Distance *(E)*,[B] in.
½	1¾	17/32	5/16	1:6	7/16
⅝	1¾	11/16	5/16	1:6	9/16
¾	1¾	13/16	5/16	1:6	21/32
⅞	1¾	15/16	5/16	1:6	25/32
1	1¾	1⅛	5/16	1:6	⅞
1⅛	2¼	1¼	5/16	1:6	1
1¼	2¼	1⅜	5/16	1:6	1 3/32
1⅜	2¼	1½	5/16	1:6	1 7/32
1½	2¼	1⅝	5/16	1:6	1 5/16

[A] Rectangular beveled washers shall conform to the dimensions shown above, except that one side may be longer than that shown for the *A* dimension.

[B] Clipped edge *E* shall not be closer than ⅞ of the bolt diameter from the center of the washer.

finished material representing each lot of washers. The chemical composition shall conform to the requirements of 4.1 and 5.1.

5.3 Individual heats of steel are not identified in the finished product.

5.4 Chemical analyses shall be performed in accordance with Methods, Practices, and Definitions A 751.

6. Mechanical Properties

6.1 Through hardened washers shall have a hardness of 38 to 45 HRC, except when zinc-coated by the hot-dip process, in which case they shall have a hardness of 26 to 45 HRC.

6.2 Carburized washers shall be carburized to a minimum depth of 0.015 in. and shall have a surface hardness of 69 to 73 HRA or 79 to 83 HR15N, except when zinc-coated by the hot-dip process, in which case they shall have a hardness of 63 to 73 HRA or 73 to 83 HR15N.

6.3 Carburized and hardened washers shall have a minimum core hardness of 30 HRC or 65 HRA.

7. Dimensions and Tolerances

7.1 All circular and clipped circular washers shall conform to the dimensions shown in Tables 2 and 4.

7.2 All square beveled and clipped square beveled washers shall conform to the dimensions shown in Tables 3 and 4. In addition, rectangular beveled and clipped rectangular beveled washers shall conform to the dimensions shown in Tables 3 and 4, except that one side may be longer than shown for the "A" dimension.

7.3 Unless otherwise stated in the inquiry or purchase order, plain (uncoated) hardened steel circular washers shall be furnished. Where corrosion-preventive treatment is required, washers shall be coated as agreed upon between the manufacturer and the purchaser.

8. Workmanship, Finish, and Appearance

8.1 Washers shall be free of excess mill scale, excess coatings and foreign material on bearing surfaces. Arc and gas cut washers shall be free of metal spatter.

9. Sampling and Number of Tests

9.1 The requirements of this specification shall be met in continuous mass production for stock, and the manufacturer shall make sample inspections to ensure that the product conforms to the specified requirements. Additional tests of individual shipments of material are not ordinarily contemplated.

9.2 When additional tests are specified in the inquiry or purchase order, a lot, for purposes of selecting test samples, shall consist of all material offered for inspection at one time that has the following common characteristics:

9.2.1 Same nominal size.

9.2.2 Same material grade.

9.2.3 Same nominal post treatment (heat treatment or coating or both).

9.3 From each lot described in 9.2, the number of specimens tested for each required property shall be as follows:

Number of Pieces in Lot	Number of Specimens
800 and under	1
801 to 8000	2
8001 to 22 000	3
Over 22 000	5

10. Test Methods

10.1 *Hardness:*

10.1.1 *Non-carburized Washers*—A minimum of two readings shall be taken 180° apart on at least one face at a minimum depth of 0.015 in.

10.1.2 *Carburized Washers*—A minimum of two readings shall be taken 180° apart on at least one face.

10.2 Hardness tests shall be performed in accordance with the Rockwell test method specified in Test Methods F 606.

TABLE 4 Washer Dimension Tolerances

	To 1½ in. Nominal Bolt Size, incl	Over 1½ in. Nominal Bolt Size, incl	Over 3 to 4 in. Nominal Bolt Size, incl
Nominal diameter of hole, in.	−0, +1/32	−0, +1/16	−0, +1/8
Nominal outside diameter, in.	±1/32	±1/16	±1/8
Flatness: max deviation from straightedge placed on cut side shall not exceed (in.)	0.010	0.015	0.032
Concentricity, in.: center of hole to outside diameter	0.030 FIR[A]	0.090 FIR[A]	0.250 FIR[A]
Burr shall not project above immediately adjacent washer surface more than (in.)	0.010	0.015	0.025

[A] Full indicator runout.

11. Inspection

11.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed to.

11.2 If other than the normal inspection for continuous mass production of parts as stipulated in 9.1 is required by the purchaser, it shall be specified in the inquiry and contract order.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

13. Certification and Test Report

13.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the latest mechanical tests of each stock size in each shipment, shall be furnished at the time of shipment.

13.2 Data contained in the certified test report shall include material grade and hardness tests.

14. Responsibility

14.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser and certifies that the fastener was manufactured, sampled, tested and inspected in accordance with this specification and meets all of its requirements.

15. Product Marking

15.1 Washers shall be marked with a symbol, or other distinguishing marks, to identify the manufacturer.

15.2 Additionally, Type 3 weathering steel washers shall be identified with the symbol "3".

15.3 Additional identification or distinguishing marks, or both, may be used by the manufacturer.

15.4 All marking symbols shall be depressed on one face of the washer.

15.5 It is possible that during the clipping of circular washers the marking symbols may be removed. This is acceptable provided that the majority of washers in the lot still display the identification marks.

16. Packaging and Package Marking

16.1 *Packaging:*

16.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

16.1.2 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

16.2 *Package Marking:*

16.2.1 Each shipping unit shall include or be plainly marked with the following information:

16.2.1.1 ASTM designation and type,

16.2.1.2 Size,

16.2.1.3 Name and brand or trademark of the manufacturer,

16.2.1.4 Number of pieces,

16.2.1.5 Purchase order number, and

16.2.1.6 Country of origin.

SUPPLEMENTARY REQUIREMENT

S1. Surface Roughness

S1.1 Washers shall have a multidirectional lay with a surface roughness not exceeding 750 μin. in height including any flaws in or on the surface.

S1.2 Burrs shall not exceed 0.01 in. in height.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this specification that have been incorporated since the last issue. For the convenience of the user, Committee F16 has highlighted those changes that may impact the use of this specification. This section may also include descriptions of the changes or reasons for the changes, or both.

(1) Section 1 was revised to include "Type 1" for carbon steel washers and "Type 3" for weathering steel washers.

(2) Added 16.1 to require Packaging in accordance with Practice D 3951 and 16.2, Package Marking.

Designation: F 606 - 90

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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If not listed in the current combined index, will appear in the next edition.

Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets[1]

This standard is issued under the fixed designation F 606; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue that has been adopted by the Department of Defense.

1. Scope

1.1 These test methods establish procedures for conducting tests to determine the mechanical properties of externally and internally threaded fasteners, washers, and rivets.

1.2 Property requirements and the applicable tests for their determination are specified in individual product standards. In those instances where the testing requirements are unique or at variance with these standard procedures, the product standard shall specify the controlling testing requirements.

1.3 These test methods describe mechanical tests for determining the following properties:

	Section
For Externally Threaded Fasteners:	3
Product Hardness	3.1
Proof Load	
Method 1, Length Measurement	3.2.3
Method 2, Yield Strength	3.2.4
Method 3, Uniform Hardness	3.2.5
Axial Tension Testing of Full-Size Product	3.4
Wedge Tension Testing of Full-Size Product	3.5
Tension Testing of Machined Test Specimens	3.6
Total Extension at Fracture Test	3.7
Single Sheer Test	3.8
For Internally Threaded Fasteners:	4
Product Hardness	4.1
Proof Load Test	4.2
Cone Proof Load Test	4.3
For Washers:	5
Through Hardened Washers	5.1
Carburized Washers	5.2
For Rivets:	6
Product Hardness	6.1
Test for Embrittlement of Metallic-Coated Externally Threaded Fasteners	7

1.4 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—A complete metric companion to Test Methods F 606 has been developed—F 606M; therefore, no metric equivalents are shown in these test methods.

2. Referenced Documents

2.1 *ASTM Standards:*

A 394 Specification for Zinc-Coated Steel Transmission Tower Bolts[2]

E 8 Test Methods of Tension Testing of Metallic Materials[3]

E 10 Test Method for Brinell Hardness of Metallic Materials[3]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[3]

E 83 Practice for Verification and Classification of Extensometers[3]

F 436 Specification for Hardened Steel Washers[2]

F 606M Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets [Metric][2]

2.2 *Military Standard:*

MIL STD 1312, Test 13 and Test 20[4]

3. Test Methods for Externally Threaded Fasteners

3.1 *Product Hardness*—For routine inspection, hardness of bolts and studs may be determined on the ends, wrench flats, or unthreaded shanks after removal of any oxide, decarburization, plating, or other coating material. Rockwell or Brinell hardness may be used at the option of the manufacturer, taking into account the size and grade of the product. For purpose of arbitration, hardness shall be determined at mid-radius of a transverse section of the product taken at a distance of one diameter from the point end of the product as specified in 3.1.1. The reported hardness shall be the average of four hardness readings located at 90° to one another. The preparation of test specimens and the performance of hardness tests for Rockwell and Brinell testing shall be in conformity with the requirements of Test Methods E 18 and E 10, respectively. For bolts, the following alternative methods of determining hardness are acceptable:

3.1.1 All grades and styles of product at mid-radius, one diameter from the end:

Rockwell—all sizes
Brinell—over 2¼ in. nominal diameter only

3.1.2 On the side of the head of a hex-head or square-head

[1] These test methods are under the jurisdiction of ASTM Committee F-16 on Fasteners and are the direct responsibility of Subcommittee F16.01 on Test Methods.
Current edition approved Aug. 31, 1990. Published October 1990. Originally published as F 606 – 79. Last previous edition F 606 – 86$^{\epsilon 2}$.

[2] *Annual Book of ASTM Standards*, Vol 15.08.
[3] *Annual Book of ASTM Standards*, Vol 03.01.
[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

product of all grades after adequate preparation to remove any decarburization:

Rockwell—all sizes
Brinell—over 1½ in. nominal diameter only

3.2 *Tension Tests*—It is preferred that bolts and studs be tested full size, and it is customary, when so testing, to specify a minimum ultimate load (or stress) in pounds-force (or pounds-force per square inch.) Paragraphs 3.2 through 3.5 apply when testing externally threaded fasteners full size. Paragraph 3.6 shall apply where the individual product specifications permit the use of machined specimens.

3.2.1 *Proof Load*—The proof-load test consists of stressing the product with a specified load that the product must withstand without measurable permanent set. Alternative tests for determining the ability of a fastener to pass the proof-load test are the yield strength test and the uniform hardness test. Either Method 1 (3.2.3), Method 2 (3.2.4), or Method 3 (3.2.5) may be used, but Method 1 shall be the arbitration method in case of any dispute as to acceptance of the product.

3.2.2 In both Methods 1 and 2, assemble the product in the fixture of the tension testing machine so that six complete threads (except for heavy hex structural bolts, which shall be based on four threads) are exposed between the grips. This is obtained by freely running the nut or fixture to the thread runout of the specimen and then unscrewing the specimen six full turns. For continuous thread bolts, at least six full threads shall be exposed between the fixture ends; however, for referee purposes, six full threads shall be exposed.

3.2.3 *Method 1, Length Measurement*—Measure the overall length of the specimen at its true center line with an instrument capable of measuring changes in length of 0.0001 in. with an accuracy of 0.0001 in. in any 0.001-in. range. The preferred method of measuring the length shall be between conical centers on the center line of the bolt or stud with mating centers on the measuring anvils. Mark the head or body of the bolt or stud so that it can be placed in the same position for all measurements. Assemble the product in the testing equipment as outlined in 3.4, and axially load to the proof load specified in the product specification. Upon release of this load, again measure the length of the bolt or stud. It shall show no permanent elongation. A tolerance (for measurement error only) of ±0.0005 in. shall be allowed between the measurement made before loading and that made after loading. Variables such as straightness, thread alignment, or measurement error could result in apparent elongation of the product when the specified proof load is initially applied. In such cases, the product may be retested using a 3 % greater load, and shall be considered acceptable if there is no difference in the length measurement after this loading within a 0.0005-in. measurement tolerance as outlined.

3.2.3.1 *Proof Load-Speed and Time of Loading*—When using Method 1, the speed of testing, as determined with a free-running cross head, shall not exceed 0.12 in./min, and the proof load shall be maintained for a period of 10 s before releasing the load.

3.2.4 *Method 2, Yield Strength*—Assemble the product in the testing equipment as outlined in 3.4. As the load is applied, measure and record the total elongation of the product or any part of it that includes the exposed threads to produce a load-elongation diagram. Determine the load or stress at an offset equal to 0.2 % of the length of bolt occupied by six full threads (except for heavy hex structural bolts, which shall be based on four threads) by the method described in 3.6.2.1.

3.2.5 *Method 3, Uniform Hardness*—The fasteners shall be tested for hardness as described in 3.1, and in addition, the hardness shall also be determined in the core. The difference between the mid-radius and core hardness shall be not more than 3 points on a Rockwell C Scale; and both readings must be within product specification.

NOTE 2—This test is valid for fasteners up to and including 1 in. in diameter. Tests are being conducted to determine values for fasteners over 1 in. in diameter.

3.3 *Bolts or Studs Too Short for Tension Testing*—Product lengths less than those shown in Table 1 for product ¼ through ¾ in. in diameter and less than three diameters in length for product above ¾ in. in diameter, or that do not have sufficient threads for proper engagement and still leave the specified number of complete threads exposed between the grips, shall be deemed too short for tension testing, and acceptance shall be based on a hardness test performed in accordance with 3.1. If tests other than product hardness are required, their requirements should be referenced in the product specification.

3.4 *Axial Tension Testing of Full-Size Products:*

3.4.1 Test bolts in a holder with the load axially applied between the head and a nut or suitable fixture (Fig. 1), either of which shall have sufficient thread engagement to develop the full strength of the product. Assemble the nut or fixture on the product, leaving six complete bolt threads exposed between the grips except for heavy hex structural bolts, which shall have four complete threads exposed between the grips.

3.4.2 Test studs by assembling one end in the threaded fixture to the thread runout. For studs having unlike threads, this shall be the end with the finer pitch thread, or with the

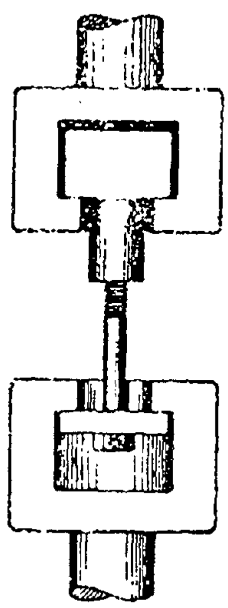


FIG. 1 Tension Testing of Full-Size Bolt

TABLE 1 Minimum Length of Product Requiring Tension Testing

Nominal Product Size, in.	Minimum Length, in.
1/4	5/8
5/16	3/4
3/8	7/8
7/16	1
1/2	1 1/8
9/16	1 1/4
5/8	1 1/2
3/4	1 3/4
7/8 and larger	3 dia

larger minor diameter. Likewise, assemble the other end of the stud in a threaded fixture, leaving six complete threads exposed between the grips. For continuous thread studs, at least six complete threads shall be exposed between the fixture ends. The maximum speed of the free-running cross head shall not exceed 1 in./min. When reporting the tensile strength of product, in pounds-force per square inch, calculate the thread stress area as follows:

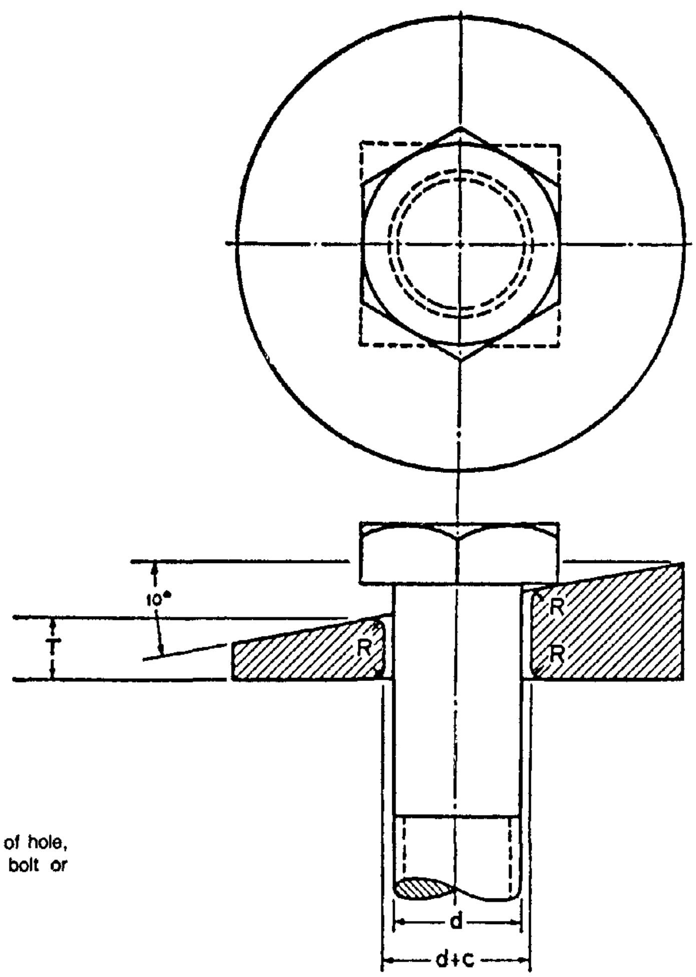
$$A_s = 0.7854\ [D - (0.9743)/n]^2$$

where:
A_s = thread stress area, in.^{2},
D = nominal diameter of bolt or stud, in., and
n = number of threads per inch.

3.4.3 To meet the requirements of the test described in 3.4.1 and 3.4.2, the product shall support a load prior to fracture not less than the minimum tensile strength specified in the product specification for its size, strength, and thread series. In addition, the failure shall occur in the body or threaded section with no failure at the junction of head and shank.

3.5 *Wedge Tension Testing of Full-Size Product*—The wedge tensile strength of a hex or square-head fastener, socket-head cap screw (with the exception of socket button or flat countersunk head products) or stud is the tensile load that the product is capable of sustaining when stressed with a wedge under the head. The purpose of this test is to obtain the tensile strength and demonstrate the "head quality" and ductility of the product.

3.5.1 *Wedge Tension Testing of Bolts*—Determine the ultimate load of the bolt as described in 3.4 except place a wedge under the bolt head. When both wedge tension and proof load testing are required by the product specification use the proof load-tested bolts for wedge testing. The wedge shall have a minimum hardness of 45 HRC for bolts and studs having an ultimate tensile strength of 150 000 psi or less, and a minimum hardness of 55 HRC for bolts and studs having a tensile strength in excess of 150 000 psi. Additionally, the wedge shall have a thickness of one half the nominal



c = clearance of hole
D = diameter of bolt or screw
R = radius or chamber
T = thickness of wedge at thin side of hole, equals one half diameter of bolt or screw
W = wedge angle (see Table 2)

FIG. 2 Wedge Test Details—Bolts

bolt diameter (measured at the thin side of the hole, see Fig. 2). The wedge shall have an included angle as shown in Table 2 for the product type being tested. The hole in the wedge shall have a clearance over the nominal size of the bolt, and its edges top and bottom shall be rounded as specified in Table 3. The minimum outside dimension of the wedge should be such that at no time during the test should any corner loading of the head of the product (adjacent to the wedge) occur. The bolt shall be tension tested to failure. To meet the requirements of this test, the bolt shall support a load prior to fracture not less than the minimum tensile strength specified in the product specification for the applicable size, grade, and thread series. In addition, the failure shall occur in the body or threaded section with no failure at the junction of head and shank.

3.5.2 *Wedge Tension Testing of Studs*—When both wedge tension and proof load testing are required by the product specifications, assemble one end of the same stud previously used for proof load testing in a threaded fixture to the thread runout. For studs having unlike threads, this shall be the end with the finer pitch thread or with the larger minor diameter. Assemble the other end of the stud in a threaded wedge to the runout and then unscrew six full turns, thus leaving six complete threads exposed between the grips, as illustrated in Fig. 3. For continuous thread studs, at least six complete threads shall be exposed between the fixture ends. The angle of the wedge for the stud size and grade shall be as specified in Table 2. Assemble the stud in the testing machine and tension test to failure, as described in 3.4. The minimum hardness of the threaded wedge shall be 45 HRC for product having an ultimate tensile strength less than 150 000 psi, and 55 HRC for product having an ultimate tensile strength in excess of 150 000 psi. The length of the threaded section of the wedge shall be equal to at least the diameter of the stud. To facilitate removal of the broken stud, counterbore the wedge. The thickness of the wedge at the thin side of the hole shall equal the diameter of the stud plus the depth of counterbore. The thread in the wedge shall have Class 3B tolerances, except when testing studs having an interference fit thread, in which case the wedge shall be threaded to provide a finger-free fit. The supporting fixture, as shown in Fig. 3, shall have a hole clearance over the nominal size of the stud, and shall have its top and bottom edges rounded or chamfered to the same limits specified for the hardened wedge in Table 3. To meet the requirements of this test, the stud shall support a load prior to fracture not less than the minimum tensile strength specified in the product specification for its size, grade, and thread series. The fracture may occur in the threaded section or in the body if the stud does not have a continuous thread.

3.6 *Tension Testing of Machined Test Specimens:*

TABLE 2 Tension Test Wedge Angles

Nominal Product Size, in.	Degrees	
	Bolts[A]	Studs and Flange Bolts
¼–1	10	6
Over 1	6	4

[A] Heat-treated bolts that are threaded one diameter or closer to the underside of the head, shall use a wedge angle of 6° for sizes ¼ through ¾ in. and 4° for sizes over ¾ in.

TABLE 3 Tensile Test Wedge Hole Clearance—Details

Nominal Product Size, in.	Nominal Clearance in Hole, in.	Nominal Radius on Corners of Hole, in.
¼–½	0.030	0.030
9/16–¾	0.050	0.060
⅞–1	0.060	0.060
1⅛–1¼	0.060	0.125
1⅜–1½	0.094	0.125
1¾–2	0.094	0.225
2¼–3	0.125	0.256

3.6.1 Where bolts and studs cannot be tested full size, conduct tests using test specimens machined from the bolt or stud (see Test Methods E 8).

3.6.1.1 Bolts and studs 9/16 in. in diameter and smaller may be machined concentric with the axis of the bolt or stud. The specimen shall have a turned section as large as feasible and shall have a gage length four times the diameter of the specimen. See Figs. 4 and 5.

3.6.1.2 Bolts and studs ⅝ in. in diameter through 1¼ in. in diameter may have their shanks machined concentric with the axis of the bolt or stud, leaving the bolt head and threaded section intact as shown in Fig. 4. Alternatively, bolts and studs ⅝ in. in diameter through 1¼ in. in diameter may have their shanks machined to a test specimen with the axis of the specimen located midway between the axis and outside surface of the bolt or stud as shown in Fig. 6. Bolts of a small cross section that will not permit taking the 0.500-in. round, 2-in. gage length test specimen shall have a turned section as large as feasible and concentric with the axis of the bolt or stud. The gage length for measuring the elongation shall be four times the diameter of the specimen. Figure 5 illustrates an example of these small-size specimens. For arbitration purposes, machined test specimens for bolts and studs ⅝ in. in diameter through 1¼ in. in diameter shall be machined with the axis of the specimen located midway between the center and outside surface.

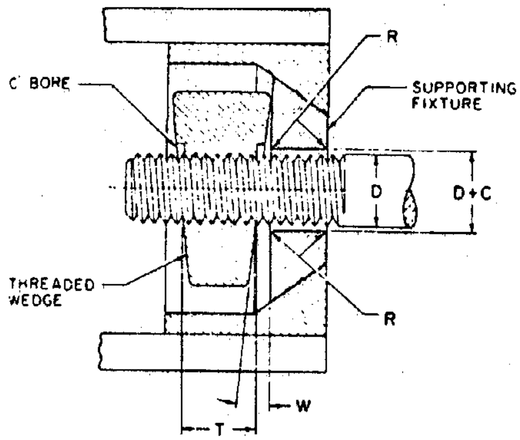
3.6.1.3 Bolts and studs 1⅜ in. in diameter and larger may have their shanks machined to the dimensions of a 0.500-in. round, 2-in. gage length test specimen with the axis of the specimen located midway between the center and outside surface of the bolt or stud as shown in Fig. 6.

3.6.1.4 Machined test specimens shall exhibit tensile strength, yield strength (or yield point), elongation, and reduction of area equal to or greater than the values of these properties specified for the product size in the applicable product specification when tested in accordance with this section.

3.6.2 *Determination of Tensile Properties:*

3.6.2.1 *Yield Point*—Yield point is the first stress in a material, less than the maximum obtainable stress, at which an increase in strain occurs without an increase in stress. Yield point is intended for application only for materials that may exhibit the unique characteristic of showing an increase in strain without an increase in stress. The stress-strain diagram is characterized by a sharp knee or discontinuity. Determine yield point by one of the following methods:

3.6.2.2 *Drop of the Beam or Halt of the Pointer Method*—In this method apply an increasing load to the specimen at a uniform rate. When a lever and poise machine is used, keep the beam in balance by running out the poise at approximately a steady rate. When the yield point of the material is



C = clearance of hole (see Table 3)
D = diameter of stud
R = radius or chamfer (see Table 3)
T = *E* plus depth of counterbore
W = wedge angle (see Table 2)
E = length of threaded section of wedge = *D*

FIG. 3 Wedge Test Details—Studs

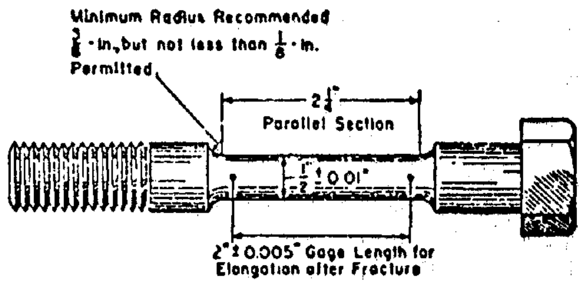


FIG. 4 Tension Test Specimen for Bolt with Turned-Down Shank

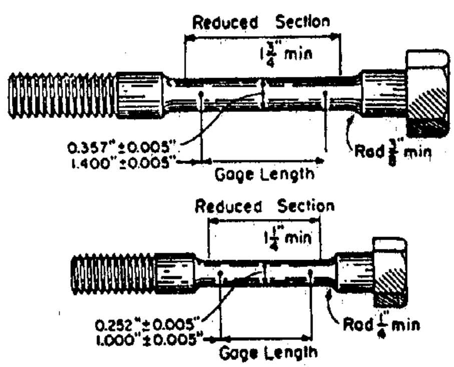


FIG. 5 Examples of Small-Size Specimens Proportional to Standard 2-in. Gage Length Specimen

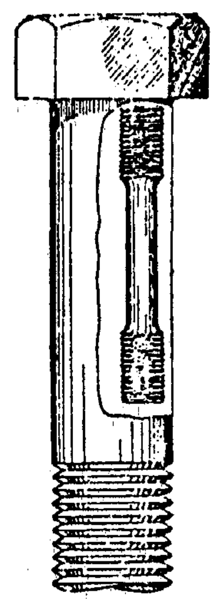


FIG. 6 Location of Standard Round 2-in. Gage Length Tension Test Specimen When Turned from Large Size Bolt

reached, the increase of the load will stop, but run the poise a trifle beyond the balance position, and the beam of the machine will drop for a brief but appreciable interval of time. When a machine equipped with a load-indicating dial is used, there is a halt or hesitation of the load-indicating pointer corresponding to the drop of the beam. Note the load at the "drop of the beam" or the "halt of the pointer" and record the corresponding stress as the yield point.

3.6.2.3 *Autographic Diagram Method*—When a sharp-kneed stress-strain diagram is obtained by an autographic recording device, take the stress corresponding to the top of the knee (Fig. 7), or the stress at which the curve drops as the yield point (Fig. 8).

3.6.2.4 *Total Extension Under Load Method*—When testing material for yield point and the test specimens may not exhibit a well-defined disproportionate deformation that characterizes a yield point as measured by the drop of the beam, halt of the pointer, or autographic diagram methods described in 3.6.2.2 and 3.6.2.3, a value equivalent to the yield point in its practical significance may be determined by the following method and may be recorded as yield point: Attach a Class C or better extensometer (Notes 3 and 4) to the specimen. When the load producing a specified extension (Note 5) is reached, record the stress corresponding to the load as the yield point, and remove the extensometer (Fig. 9).

NOTE 3—Automatic devices are available that determine the load at the specified total extension without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated. Multiplying calipers and other such devices are acceptable for use provided their accuracy has been demonstrated as equivalent to a Class C extensometer.

NOTE 4—Reference should be made to Practice E 83.

NOTE 5—For steel with a specified yield point not over 80 000 psi, an appropriate value is 0.005 in./in. of gage length. For values above

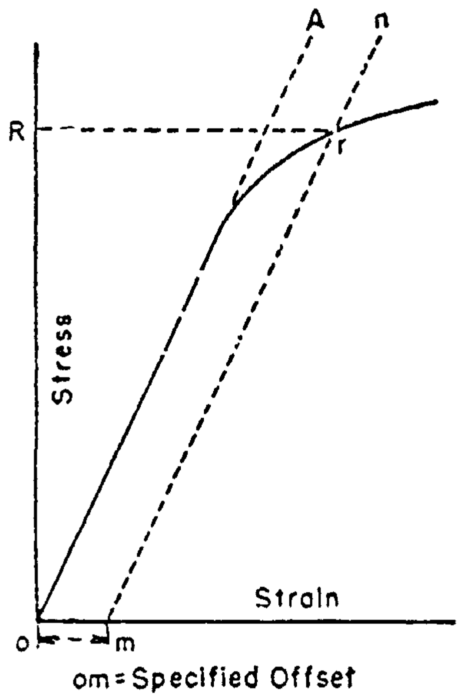


FIG. 7 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

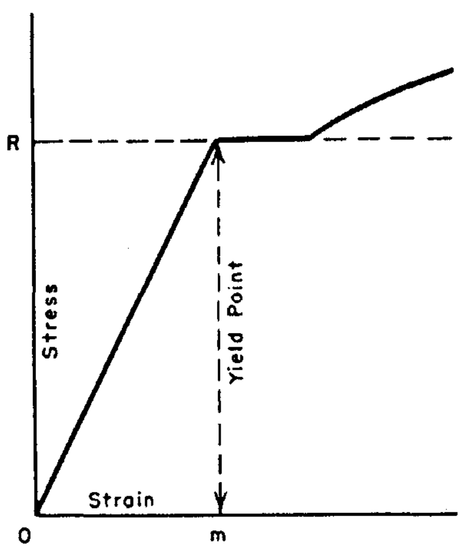


FIG. 8 Stress-Strain Diagram showing Yield Point Corresponding with Top of Knee

80 000 psi, this test method is not valid unless the limiting total extension is increased.

3.6.3 *Yield Strength*—Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain, percent offset, total extension under load, etc. Determine yield strength by one of the following methods:

3.6.3.1 *Offset Method*—To determine the yield strength by the "offset method," it is necessary to secure data (autographic or numerical) from which a stress-strain diagram may be drawn. Then on the stress-strain diagram (Fig.

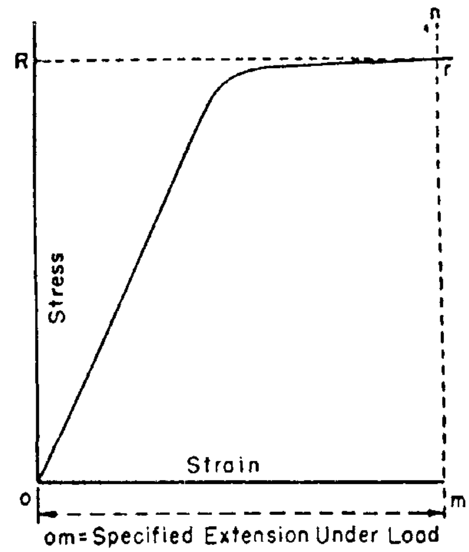


FIG. 9 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method

7) lay off *Om* equal to the specified value of the offset, draw *mn* parallel to *OA*, and thus locate *r*. The yield strength load *R* is the load corresponding to the highest point of the stress-strain curve before or at the intersection of *mn* with *r*. In reporting values of yield strength obtained by this method, the specified value of "offset" used should be stated in parentheses after the term yield strength, thus:

Yield strength (0.2 % offset) = 52 000 psi

In using this method, a minimum extensometer magnification of 250 to 1 is required. A Class B1 extensometer meets this requirement (see Note 4). See also Note 6 for automatic devices.

3.6.3.2 *Extension Under Load Method*—For tests to determine the acceptance or rejection of material whose stress-strain characteristics are well known from previous tests of similar material in which stress-strain diagrams were plotted, the total strain corresponding to the stress at which the specified offset (see Note 7) occurs will be known within satisfactory limits. The stress on the specimen, when this total strain is reached, is the value of the yield strength. The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Notes 3 and 4).

NOTE 6—Automatic devices are available that determine offset yield strength without plotting a stress strain curve. Such devices may be used if their accuracy has been demonstrated.

NOTE 7—The appropriate magnitude of the extension under load will obviously vary with the strength range of the particular material under test. In general, the value of extension under load applicable to any material strength level may be determined from the sum of the proportional strain and the plastic strain expected at the specified yield strength. The following equation is used:

$$\text{Extension under load, in./in. of gage length} = (YS/E) = r$$

where:

YS = specified yield strength, psi,
E = modulus of elasticity, psi, and
r = limiting plastic strain, in./in.

3.6.4 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load the specimen sustains during a tension test by the original cross-sectional area of the specimen.

3.6.5 *Elongation:*

3.6.5.1 Fit the ends of the fractured specimen together carefully and measure the distance between the gage marks to the nearest 0.01 in. for gage lengths of 2 in. and under, and to the nearest 0.5 % of the gage length for gage lengths over 2 in. A percentage scale reading to 0.5 % of the gage length may be used. The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. In reporting elongation values, give both the percentage increase and the original gage length.

3.6.5.2 If any part of the fracture takes place outside of the middle half of the gage length or in a punched or scribed mark within the reduced section, the elongation value obtained may not be representative of the material. If the elongation so measured meets the minimum requirements specified, no further testing is indicated, but if the elongation is less than the minimum requirements, discard the test and retest.

3.6.6 *Reduction of Area*—Fit the ends of the fractured specimen together and measure the mean diameter or the width and thickness at the smallest cross section to the same accuracy as the original dimensions. The difference between the area thus found and the area of the original cross section expressed as a percentage of the original area, is the reduction of area.

3.7 *Total Extension at Fracture Test:*

3.7.1 The extension at fracture (A_L) test shall be carried out on stainless steel and nonferrous products (bolts, screws, and studs) in the finished condition, with lengths equal to or in excess of those minimums listed in Table 1.

3.7.2 The products to be tested shall be measured for total length (L_1) as described in 3.7.2.1 and shown in Fig. 10.

3.7.2.1 Mark both ends of the bolt, screw, or stud using a permanent marking substance such as bluing so that measuring reference points for determining total length L_1 and L_2 are established. Using an open-end caliper and steel rule or other device capable of measuring to within 0.010 in., determine the total length of the product as shown in Fig. 10.

3.7.3 The product under test shall be screwed into the threaded adapter to a depth of one diameter (see Fig. 1) and load applied axially until the product fractures. The maximum speed of the free-running cross head shall not exceed 1 in./min.

3.7.4 After the product has been fractured in accordance with 3.7.3, the two broken pieces shall be fitted closely together and the overall length (L_2) measured (see 3.7.2.1 and Fig. 10). The total extension at fracture shall then be calculated as follows:

$$A_L = L_2 - L_1$$

3.7.5 The value obtained shall equal or exceed the minimum values shown in the applicable specification for the product and material type.

3.8 *Single Shear Test:* (Note 8) This test is intended to determine the ability of a fastener to withstand a predetermined load when applied transversely to the axis of the fastener. Shear is defined as an action or stress caused by applied forces that causes two adjacent parts of a body to slide on each other to cause separation. Shear tests may be conducted in either tension-type or compression-type single shear fixture.

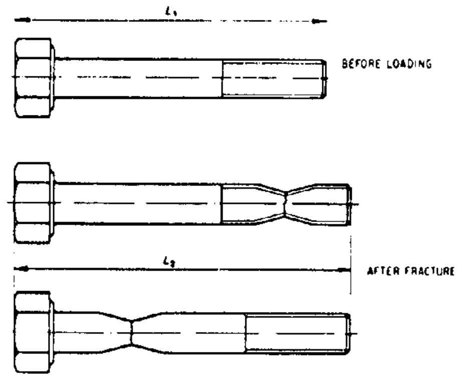


FIG. 10 Determination of Total Extension at Fracture (A_L) (only Screw Product Shown)

3.8.1 The specimen shall be tested using hardened steel plates of sufficient thickness to preclude bearing failure. Holes in the shear plates shall be 1/16 in. larger than the nominal thread diameter of the test bolt and the holes shall be chamfered 0.010 in. to relieve sharp edges. Shear plates shall be prevented from separating by means of a suitable jig or by using a nut on the test bolt tightened finger tight.

3.8.2 The test specimen, when assembled in the shear jig, shall be mounted in a tensile-testing machine capable of applying load at a controllable rate. The grips shall be self-aligning and care shall be taken when mounting the specimen to assure that the load will be transmitted in a straight line transversely through the test bolt. Load shall be applied and continued until failure of the bolt. Speed of testing as determined with a free-running cross head shall not be less than 1/4 in. nor greater than 1/2 in. per min.

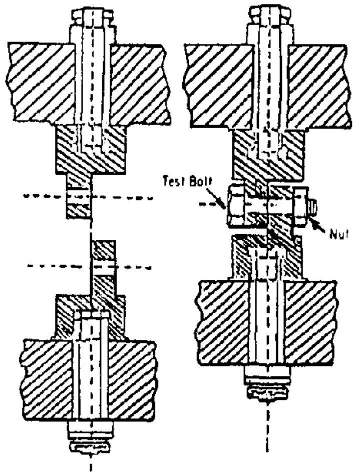
3.8.3 The maximum load applied to the specimen, coincident with or prior to bolt failure shall be recorded as the shear strength of the bolt. At the discretion of the testing activity, tests need not be continued to destruction provided that the specimen supports, without evidence of bolt failure, the minimum load specified.

3.8.4 A typical test fixture for tension shear testing is shown in Fig. 11.

NOTE 8—This single-shear test is primarily used for testing Specification A 394 tower bolts which range in size from 1/2 through 1 in. diameter. For general use, the shear test practices and fixturing found in MIL STD 1312 Test 13 is used for double shear and Test 20 may be used for single shear.

4. Test Methods for Internally Threaded Fasteners

4.1 *Product Hardness*—For routine inspection, hardness of nuts may be determined on the bearing face or wrench flats after removal of any plating or coating. Rockwell or Brinell hardness may be used at the option of the manufacturer, taking into account the size and grade of the nut. The reported hardness shall be a minimum of two hardness readings taken 180° apart halfway between the major diameter of the thread and one corner, or, if applicable, on a wrench-face one third of the distance from a corner to the center of the wrench face. In preparing the surface, remove sufficient material to assure elimination of any oxide, decarburization, coating, or other surface irregularities. The



Open Jig Test Bolt Assembled

FIG. 11 Typical Single Shear Fixture (Tension Type)

preparation of test specimens and the performance of hardness tests for Rockwell and Brinell testing shall be in conformity with the requirements of Test Methods E 18 and E 10, respectively. For purposes of arbitration or for nuts too large for full-size testing, hardness (see 4.1.1.4) shall be taken as described in 4.1.1.

4.1.1 Nuts to be tested need not be threaded, but shall be part of the manufacturing lot that was formed (in the case of heat-treated nuts, formed and heat-treated) with the product to be shipped. For purpose of testing, sample nuts or nut blanks shall be sectioned laterally at approximately one half of the nut height. For standard hex, heavy hex, and square nuts, the half of the nut not to be tested may be discarded. For special nuts, the consumer may require as part of his inquiry and purchase order that both halves of the sample nut shall be permanently marked so as to identify that both halves are from the same nut. The half not tested shall be made available to the consumer at the time of first product shipment, if specified by the customer on the purchase order.

4.1.1.1 *Nonheat-Treated Nuts* (see Fig. 12)—The section of the sample nuts to be tested shall be prepared and tested in accordance with 4.1 except that the two readings taken 180° apart shall be at the core (halfway between the major diameter if threaded, or blank hole if not threaded) and the corner of the nut. The average of the two readings shall be the hardness of the nut, and in addition shall be within the hardness values listed in the product specification.

4.1.1.2 *Heat-Treated Nuts* (see Fig. 13)—The section of the sample nuts to be tested shall be prepared and tested in accordance with 4.1 except that two sets of three readings 180° apart shall be taken. The three readings shall be taken across the section of the nut at the following positions:

Position 1—as close to the major diameter, if threaded, or hole side wall if the nut is blank, as possible, but no closer than two times the indent diameter.

Position 2—at the core (halfway between the major diameter (if threaded) or hole side wall (if not threaded or blank)) and the corner of the nut.

Position 3—as close to the corner of the nut as possible, but no closer than two times the indent diameter.

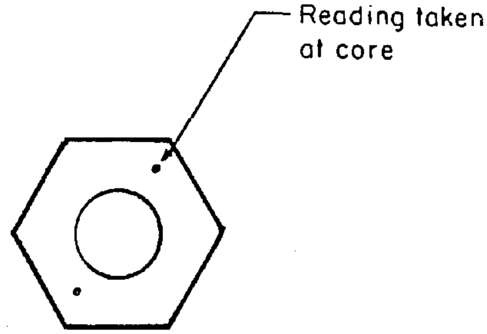


FIG. 12 Nonheat-Treated Nut

4.1.1.3 All readings shall be within the hardness values listed in the product specification. The average of all readings shall be considered as the hardness of the nut. All readings shall be conducted on a Rockwell machine.

4.1.1.4 Nuts exhibiting a proofload in excess of 160 000 lb may be considered, at the option of the manufacturer, as too large for full-size testing. Full-size testing is recommended whenever possible.

4.2 *Proof Load Test*—Assemble the nut to be tested on a hardened threaded mandrel (4.2.2) or a test bolt (4.2.1) as illustrated in Fig. 14(*a*) Tension Method or 14(*b*) Compression Method. The hardened test mandrel and the tension method shown in Fig. 14(*a*) shall be mandatory as a referee if arbitration is necessary. Apply the specified proof load for the nut against the nut. The nut shall resist this load without stripping or rupture, and shall be removable from the test bolt or mandrel by the fingers after the load is released. Occasionally it may be necessary to use a manual wrench or other means to start the nut in motion. Use of such means is permissible, provided the nut is removable by the fingers following the initial loosening of not more than one-half turn of the nut. If the threads of the mandrel or test bolt are damaged during the test, discard the test.

4.2.1 The test bolt shall have threads appropriate to the standard specified for the nut being tested and shall have a yield strength in excess of the specified proof load of the nut being tested.

4.2.2 Mandrels shall have a hardness of 45 HRC minimum and shall have threads conforming to Class 3A except that the maximum major diameter shall be the minimum major diameter plus 0.002 in. or 0.25 times the major diameter tolerance (whichever is greater) of Class 3A threads.

4.2.3 The proof load shall be determined at a free running cross head speed not exceeding 1.0 in/minute and shall be

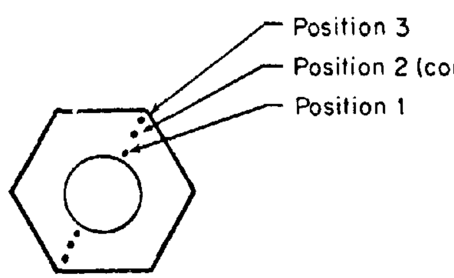
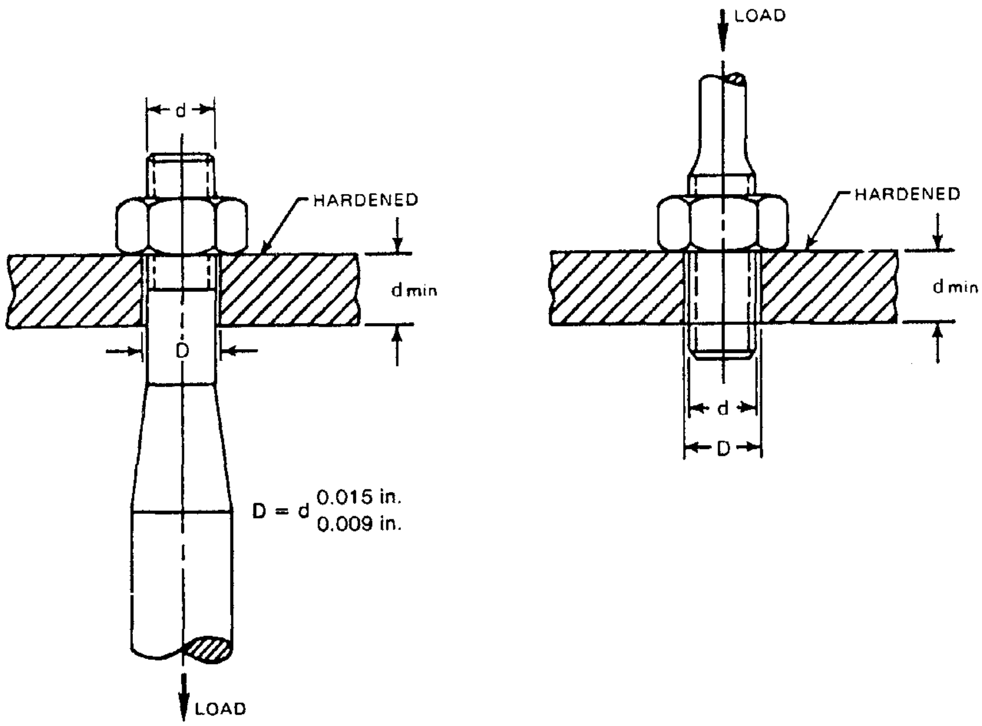


FIG. 13 Heat-Treated Nut



(a) Tension Method (b) Compression Method

FIG. 14 Proof Load Testing—Nuts

held at load for 10_s minimum

4.3 *Cone Proof Load Test*—Perform this test using a conical washer and threaded mandrel (as illustrated in Fig. 15) to determine the influence of surface discontinuities (that is, forging cracks and seams) on the load-carrying ability of hardened steel nuts through 1½ in. in diameter by introducing a simultaneous dilation and stripping action of the nut. The mandrel shall conform to the requirements of 4.2.2. The conical washer shall have a hardness of 57 HRC minimum and a hole diameter equivalent to the nominal diameter of the mandrel +0.002, −0.000 in. The contact point of the cone shall be sharp for nut sizes ½ in. and less. For sizes over ½ in., the point shall be flat and 0.015 ± 0.001 in. in width. Assemble the nut and the conical washer on the mandrel, and apply the cone proof load for the nut against the nut. The speed of testing as determined with a free-running cross head shall be a maximum of 0.12 in./min. Apply the proof load for 10 s. Compute the cone proof load of a nut as follows:

$$CPL = (1 - 0.30D) \times f \times A_s$$

where:

CPL = cone proof load, lb,
D = nominal diameter of nut, in.,
f = specified proof stress of nut, psi,
A_s = tensile stress area of nut, in.^{2},
= $0.7854\,[D - (0.9743/n)]^2$, and
n = threads per inch.

To meet the requirements of the cone proof load test, the nut shall support its specified cone proof load without stripping or rupture.

5. Test Methods for Washers

5.1 *Through Hardened Washers:*

5.1.1 *Surface Hardness*—Take measurements on a flat portion of the washer after lightly grinding or polishing to ensure accurate reproducible readings. Take two readings 180° apart on at least one face of the washer.

5.1.2 *Core Hardness*—Take minimum of two readings 180° apart on at least one face at a minimum depth of 0.015 in.

5.2 *Carburized Washers:*

5.2.1 *Surface Hardness*—Measurements shall be taken on a flat portion of the face of the washer in two areas, 180° apart, using methods that prevent penetration into the core material.

5.2.2 *Core Hardness*—A minimum of two readings shall be taken 180° apart on at least one face of the washer at a depth greater than the actual depth of case.

5.2.3 *Depth of Case*—Measurements of case depth shall be taken at a cross section through the rim of the washer which has been ground and etched to define the case area.

5.3 *Stainless Steel and Nonferrous Washers*—Surface hardness, core hardness, temper designations, or other hardness values as required by the product specifications, shall be tested in accordance with the methods found in individual material specifications.

5.4 Perform all hardness tests in accordance with those requirements for Rockwell hardness testing. The preparation of test specimens and the performance of hardness tests shall be in conformity with the requirements of Test Methods E 18.

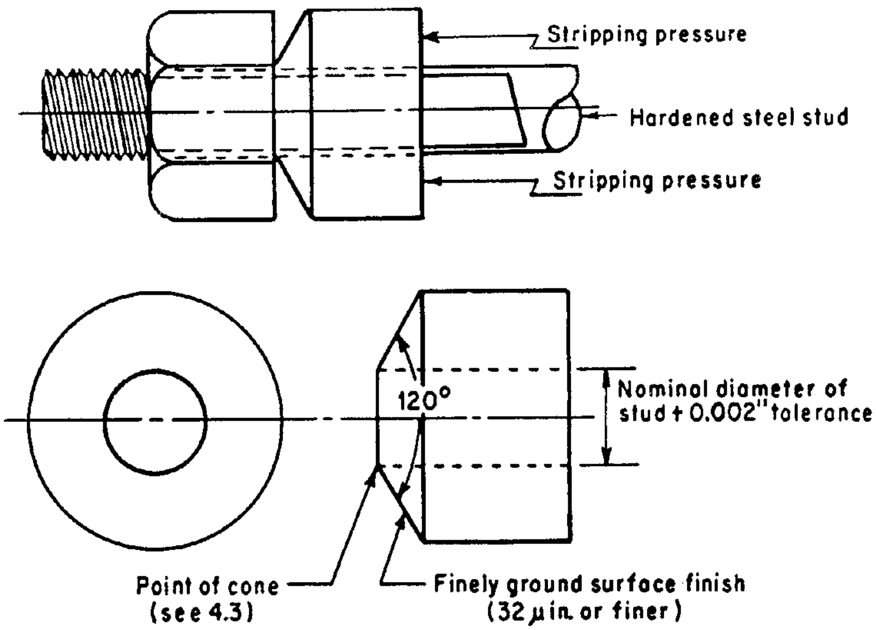
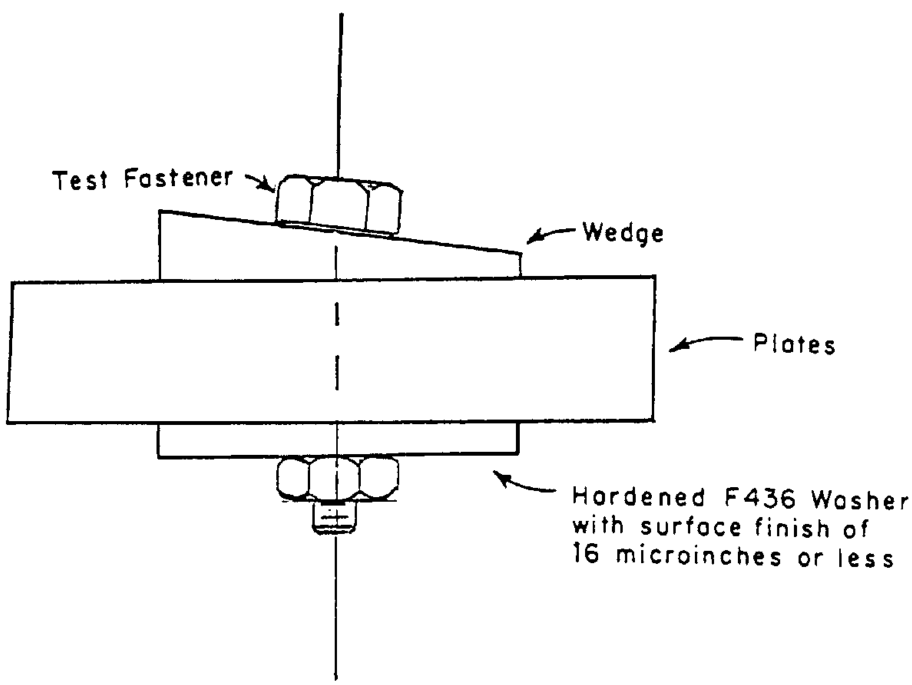


FIG. 15 Cone-Proof Test



NOTE 1—For expedience sake the test fixture shown above reflects a single bolt under load. It should be noted, however, that test fixtures with multiple test locations are acceptable.

NOTE 2—Work is continuing on this test method and revisions are anticipated. Additionally caution should be taken when applying this test procedure. The heads of embrittled fasteners may suddenly break off and become flying projectiles capable of causing serious injury or blinding.

FIG. 16 Test Fixture

6. Rivets

6.1 *Product Hardness*—Determine hardness at the mid-radius of a transverse section of the product taken at a distance of one diameter from the point end of the rivet. Use either Brinell or Rockwell hardness tests at the option of the manufacturer, and measure as described in 3.1.1.

7. Test for Embrittlement of Metallic Coated Externally Threaded Fasteners

7.1 This is one test method for determining if embrittlement exists in a metallic coated externally threaded fastener covered by the product specifications of ASTM Committee F-16.

7.2 The test fastener shall be installed in a test fixture (see Note 1 in Fig. 16) with the head positioned against the wedge, assembled with a nut, and tensioned (via the nut only) by any means capable of measuring tensile load. The torque method described in 7.3 is one such method. The test samples shall be tensioned to 75 % of their specified minimum ultimate tensile strength. For studs with different thread pitches on either end, the finer thread pitch end shall be assembled with a nut and tested as the head end of the fastener.

7.2.1 The assembly shall remain in this tightened state for not less than 48 h, after which the test fastener shall be visually examined for embrittlement-induced failure, such as missing head.

7.2.2 The joint shall then be disassembled and the test fastener visually examined using a minimum of 20 power magnification for evidence of embrittlement failure, such as transverse cracks in the shank, threads or at the junction of head to shank.

7.2.3 For disassembly, if the torque method of tightening is used, torque shall be applied in the ON direction until the nut rotates a noticeable amount. The retightening torque with the nut in motion shall be measured and shall be no less than 90 % of the initial tightening torque.

7.2.4 If a direct tension method of tightening is used, then the loss of clamping strength (in pounds) over the test period shall be no more than 10 % of the initial clamping load.

TABLE 4 Test for Embrittlement Wedge Angles, Degrees

Nominal Size of Fastener, dia	Studs and Fasteners with Unthreaded Lengths, Less Than 2 dia	Fasteners with Unthreaded Lengths, 2 dia and Longer
1/4 to 3/4 in.	4	6
Over 3/4 to 1-1/2 in.	0	4

7.3 The test fixture shall comprise a hardened wedge (7.3.1), a plate(s) (7.3.2), and a hardened washer (7.3.3). (See Fig. 16.)

7.3.1 The wedge shall have an angle as specified in Table 4. Other dimensions and properties shall be in conformance with hardened wedges described in 3.5.1.

7.3.2 The plate(s) shall be steel and have a thickness such that, after installation and tightening, a minimum of three full threads of the test fastener will be in the grip. The hole in the plate(s) shall be as close to the major diameter of the fastener being tested as practical but not greater than the hole in the hardened washer (7.2.3).

7.3.3 The hardened washer shall be in conformance with Specification F 436.

7.4 If the torque method of tightening is used, the tightening torque shall be determined using a load-measuring device capable of measuring the actual tension induced in a fastener as the fastener is tightened. Three fasteners from the test lot shall be selected at random. Each shall be assembled into the load-measuring device, mated with a nut, and the nut tightened until a load equal to 75 % of the specified minimum ultimate tensile strength of the fastener is induced. The torque required to induce this load shall be measured and the arithmetic average of the three measured torques shall be the tightening torque. The surface against which the nut is torqued should be similar in hardness and finish to that of the test fixture (16) and use of a hardened washer (7.3.3) is recommended.

7.5 To meet the requirements of this test the fastener shall show no evidence of embrittlement failure when visually examined and the retightening torque shall not be less than 90 % of the initial tightening torque.

Designation: F 959 – 90

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners[1]

This standard is issued under the fixed designation F 959; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers the chemical, mechanical, and dimensional requirements for compressible-washer-type direct tension indicators capable of indicating the achievement of a specified minimum bolt tension in a tightened structural bolt.

1.2 Two types of direct tension indicators in sizes ½ to 1½ in., incl in diameter are covered:

1.2.1 *Type 325*—Indicators for use with A 325 bolts, and

1.2.2 *Type 490*—Indicators for use with A 490 bolts.

1.3 The indicators are intended for installation under either a bolt head or a hardened washer.

1.4 If direct tension indicators are used under the turned element, a hardened round steel washer shall be used between the direct tension indicator and the turned element.

2. Referenced Documents

2.1 *ASTM Standards:*

A 325 Specification for High-Strength Bolts for Structural Steel Joints[2]

A 490 Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength[2]

B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel[3]

D 3951 Practice for Commercial Packaging[4]

2.2 *Research Council on Structural Connections:*

Specification for Structural Joints Using ASTM A 325 or A 490 Bolts[5]

2.3 *ANSI Standards*[6]*:*

B18.2.1 Square and Hex Bolts and Screws

B18.2.2 Square and Hex Nuts

3. Terminology

3.1 *Description of Term Specific to This Standard:*

3.1.1 *compressible washer-type direct tension indicator*—a washer-type element inserted under the bolt head or hardened washer, having the capability of indicating the achievement of a required minimum bolt tension by the degree of indicator plastic deformation.

4. Ordering Information

4.1 Orders for indicators under this specification shall include the following:

4.1.1 Quantity (number of pieces),

4.1.2 Name of product,

4.1.3 Size, that is, bolt diameter,

4.1.4 ASTM designation and year of issue,

4.1.5 Type required, A 325 or A 490 (see 1.2),

4.1.6 Zinc Coating—Specify "mechanically deposited," if required (see 5.4).

4.1.7 Epoxy Coating—Specify "baked epoxy coating on mechanically deposited zinc," if required (see 5.4).

4.1.8 Source inspection, if required (see Section 13),

4.1.9 Specify if certificate of compliance or test reports are required (see Section 15), and

4.1.10 Any special requirements.

5. Materials and Manufacture

5.1 Steel used in the manufacture of direct tension indicators shall be produced by the open-hearth, basic-oxygen, or electric-furnace process.

5.2 *Design:*

5.2.1 Direct tension indicators shall have a configuration produced by extrusion, punching, pressing, or similar forming, to permit a measurable decrease in thickness when placed in compression.

5.2.2 The design shall be such that the degree of plastic deformation shall indicate the tension in a tightened structural bolt.

5.3 *Heat Treatment*—The indicators shall be quenched and tempered.

5.4 *Protective Coatings:*

5.4.1 Unless otherwise specified, the indicators shall be furnished "plain" with the "as fabricated" surface finish without protective coatings.

5.4.2 When "zinc coated" is specified, the indicators shall be zinc coated by the mechanical deposition process in accordance with the requirements of Class 50 of Specification B 695.

5.4.3 When "baked epoxy" is specified, the epoxy shall be 0.001 to 0.002 in. thick applied over the zinc coating specified in 5.4.2. The epoxy shall not flake off exposed surfaces during installation.

[1] This specification is under the jurisdiction of ASTM Committee F-16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets and Washers.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as F 959 – 85. Last previous edition F 959 – 89.

[2] *Annual Book of ASTM Standards*, Vol 15.08.

[3] *Annual Book of ASTM Standards*, Vols 02.05 and 15.08.

[4] *Annual Book of ASTM Standards*, Vol 15.09.

[5] Available from Research Council on Structural Connections, % Old Dominion University, Civil Engineering Technology, Norfolk, VA 23508-8547.

[6] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

* A Summary of Changes section appears at the end of this specification.

TABLE 1 Chemical Requirements

Element	Composition, %	
	Heat Analysis	Product Analysis
Carbon	0.30–0.50	0.27–0.53
Manganese	0.50–0.90	0.47–0.93
Phosphorus, Max	0.040	0.048
Sulfur, Max	0.050	0.058
Silicon	0.15–0.35	0.12–0.38

6. Chemical Composition

6.1 The indicator material shall conform to the chemical composition specified in Table 1.

6.2 Product analysis may be made by the purchaser from finished indicators representing each lot. The chemical composition shall conform to the requirements in Table 1, Product Analysis.

7. Performance Requirements

7.1 *Bolt Tension:*

7.1.1 When indicators are installed in a structural joint with A 325 or A 490 bolts and compressed to an average gap equal to or less than the gaps specified in Table 2, the induced bolt tension shall be equal to or greater than that specified in Table 3, columns headed "Minimum Required Bolt Tension" for the applicable grade.

7.1.2 Average gap shall be measured as specified in Table 4.

7.1.3 Tests to determine compliance with 7.1.1 shall be conducted in accordance with Section 12.

8. Dimensions

8.1 The indicators shall conform to the dimensions specified in Table 5.

8.2 Die grooves, burrs, and excessive swelling under bolt heads, sometimes found in hot forged bolts, may prevent the tension indicator from properly contacting the underside of the bolt head. The use of indicators in an "under the nut" assembly (Fig. 1) will overcome this problem.

9. Workmanship, Finish, and Appearance

9.1 The indicators shall be commercially smooth and free of burrs, laps, seams, cracks, excess mill scale, and foreign material on bearing surfaces, and other injurious material or manufacturing defects which would make them unsuitable for the intended application.

TABLE 2 Tension Indicator Average Gaps to Give Required Minimum Bolt Tension

Tension Indicator Installation (see Fig. 1) and Bolt and Indicator Finish	Average Gap, in.	
	A 325	A 490
Under Bolt Head		
Plain bolts and indicators	0.015	0.015
Zinc coated bolts and indicators[A]	0.005	. . .
Plain bolts and either zinc coated or epoxy coated indicators[A]	0.005	. . .
Under Turned Element		
Plain hardened washers and indicators	0.005	0.005

[A] Coated indicaters shall not be tested under the turned element.

TABLE 3 Fastener Tension and Compression Load

Bolt Size, Nominal, in.	Minimum Required Bolt Tension[A] Thousands of Pounds, (kips), min		Compression Load,[B] in Testing Device, Thousands of Pounds, (kips)	
	A 325 Bolts	A 490 Bolts	Type 325	Type 490
½	12	15	12–14	15–18
⅝	19	24	19–23	24–29
¾	28	35	28–34	35–42
⅞	39	49	39–47	49–59
1	51	64	51–61	64–77
1⅛	56	80	56–67	80–96
1¼	71	102	71–85	102–122
1⅜	85	121	85–102	121–145
1½	103	148	103–124	148–178

[A] Excerpt from the Specification for Structural Joints Using ASTM A 325 or A 490 Bolts. Approved by the Research Council on Structural Connections of the Engineering Foundation.

[B] Minimum values are equal to 70 % of specified minimum tensile strengths of bolts, rounded to the nearest kip. Maximum values are 120 % of the minimum values rounded to the nearest kip.

TABLE 4

NOTE 1—To measure average bolt-head-to-washer or washer-to-washer gap at minimum values of required bolt load with a pointed feeler gage, the feeler gage must enter at least one half the number of places where it is applied around the indicator circumference (at maximum values of required bolt load, the feeler gage must not enter at least one half the number of applied places).

NOTE 2—A 1:20 bevel is maximum permitted on the outer faces of bolted parts.

Number of Protrusions on Load Indicator Washer	Number of Places Feeler Gages Must Be Applied
4	4
5	4
6	6
7	6
8	8
9	8

10. Number of Tests and Retests

10.1 *Responsibility:*

10.1.1 The indicator manufacturer shall inspect each lot of direct tension indicators prior to shipment in accordance with the quality assurance procedures described in 10.2.

10.1.2 The purpose of a lot inspection testing program is to ensure that each lot conforms to the requirements of this specification. For such a plant to be fully effective, it is essential that following delivery the purchaser continue to maintain the identification and integrity of each lot until the product is installed in its service application.

10.2 *Production Lot Method:*

10.2.1 All direct tension indicators shall be processed in accordance with a lot identification control-quality assurance plan. The manufacturer shall identify and maintain the integrity of each production lot of direct tension indicators from raw material selection through all processing operations and treatments to final packing and shipment. Each lot shall be assigned its own lot-identification number, each lot shall be tested, and the inspection test reports for each lot shall be retained.

10.2.2 A production lot, for purposes of assigning an identification number and from which test samples shall be selected, shall consist of all direct tension indicators processed essentially together through all operations to placing in

TABLE 5 Dimensions

Bolt Size, in.	Type A 325					Type A 490					All Types		
	Outside Diameter, in.		Number of Protrusions (equally spaced)	Thickness in.		Outside Diameter in.		Number of Protrusions (equally spaced)	Thickness in.		Inside Diameter in.		Protrusion Outer Limit Diameter, in. (see Fig. 3)
	Min	Max		Without Protrusion Min	With Protrusion Max	Min	Max		Without Protrusion Min	With Protrusion Max	Min	Max	Max
1/2	1 1/8	1 3/16	4	0.104	0.180	1 5/16	1 3/8	5	0.104	0.180	17/32	9/16	7/8
5/8	1 5/16	1 3/8 ft	4	0.126	0.220	1 9/16	1 5/8	5	0.126	0.220	21/32	11/16	1 1/16
3/4	1 9/16	1 5/8 ft	5	0.142	0.240	1 11/16	1 3/4	6	0.142	0.240	25/32	13/16	1 1/4
7/8	1 13/16	1 7/8	5	0.142	0.240	1 15/16	2	6	0.158	0.260	29/32	15/16	1 7/16
1	1 15/16	2	6	0.158	0.270	2 3/16	2 1/4	7	0.158	0.270	1 1/32	1 1/16	1 5/8
1 1/8	2 1/16	2 1/8	6	0.158	0.270	2 7/16	2 1/2	7	0.158	0.280	1 11/64	1 15/64	1 13/16
1 1/4	2 3/16	2 1/4	7	0.158	0.270	2 11/16	2 3/4	8	0.158	0.280	1 19/64	1 23/64	2
1 3/8	2 7/16	2 1/2 ft	7	0.158	0.270	2 15/16	3	8	0.158	0.280	1 29/64	1 33/64	2 3/16
1 1/2	2 11/16	2 3/4	8	0.158	0.270	3 3/16	3 1/4	9	0.158	0.280	1 37/64	1 40/64	2 3/8

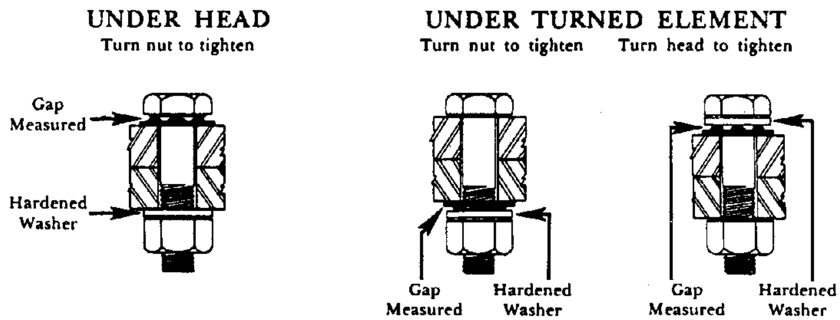

FIG. 1 Assembly of Indicator for Bolting Installations

the shipping container that are of the same nominal size, produced from the same mill heat of steel, and heat treated in the same heat treatment cycle.

10.2.3 From each production lot, the minimum number of tests shall be as follows:

Number of Pieces In Production Lot	Sample Size	Acceptance Number	Rejection Number
To 35 000	8	0	1
35 000 to 250 000	13	0	1
250 000 and over	32	0	1

10.2.4 When tested in accordance with the required sampling plan, a lot shall be rejected if any of the test specimens fail to meet the applicable test requirements.

10.3 *Retests*—If direct tension indicators are heat treated, coated, or otherwise altered by a subcontractor or manufacturer subsequent to testing, they shall be retested in accordance with 10.2 prior to shipment to the purchaser.

11. Specimen Preparation

11.1 Indicators for tests shall be tested full size "as received" without any special preparation.

12. Test Methods

12.1 *Equipment and Calibration:*

12.1.1 The indicators shall be tested in a device capable of determining their performance characteristics.

12.1.2 The testing device or its load-measuring components shall be calibrated at least once per year. The calibration test data shall be retained.

12.2 *Procedure:*

12.2.1 The indicators shall be tested as follows:

12.2.1.1 Place the indicator in the testing device.

12.2.1.2 Apply a compression load to each indicator in the test sample until the average gap between the testing device bearing block and indicator, or the underside of the bolt head and indicator (see Fig. 2), measures 0.015 in. for a plain finish indicator, or 0.005 in. if a coated indicator is tested under a bolt head (see Table 2). Only zinc coated indicators shall be tested under heads of zinc coated bolts. When testing either zinc coated or epoxy coated indicators with plain finish bolts, the indicator shall be positioned under the bolt head. A pointed feeler gage is used when measuring average gap under a bolt head per instructions in Table 4.

12.2.1.3 When testing with a bearing block, surfaces must be parallel. With this method, the gap can also be measured with a dial gage reacting on a surface in the center of the indicator support block, which surface correlates exactly with the flat surface of the indicator (see Fig. 2).

12.2.1.4 Read the compression load.

12.2.1.5 Indicators showing a compression load within the range for the applicable type in Table 3, columns headed "Compression Load in Testing Device" are acceptable. Indicators showing a compression load outside the ranges are unacceptable and the lot represented shall be rejected.

12.2.1.6 Record the compression load and average gap opening.

12.3 *Field Testing*—Calibrated field testing devices may be used at the discretion of the users. In the event of controversy, the referee method is to test in a compression or

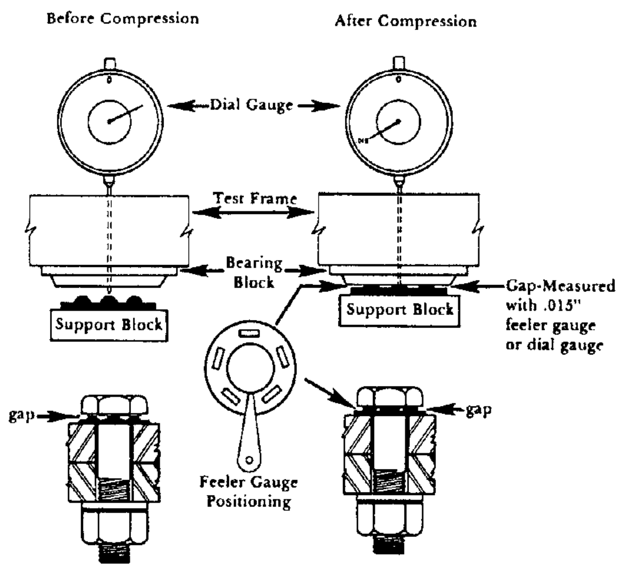

FIG. 2 Assemblies for Testing Indicator

universal testing machine and in accordance with 12.1 and 12.2.

13. Inspection

13.1 If the inspection described in 13.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

13.2 The inspector representing the purchaser shall have free entry to all parts of the manufacturer's works that concern the manufacture of the indicators ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the indicators are being furnished in accordance with this specification. All tests and inspections required by this specification that are requested by the purchaser's representative shall be made before shipment and shall be conducted as not to interfere unnecessarily with the operation of the plant.

14. Rejection

14.1 Indicators that fail to conform to the requirements of this specification shall be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

15. Certification

15.1 When specified on the order, the manufacturer shall furnish a "test report" as described in 15.2 or a "certificate of compliance" as described in 15.3, whichever is required.

15.2 When "test reports" are required, the manufacturers shall furnish a test report for each production lot from which indicators are supplied to fill a shipment. The report shall show the heat number (to assure that the chemical composition is on record and could be furnished upon request), test load, gap, nominal size, production lot identification number, ASTM designation and type, and purchase order number.

15.3 When "certificates of compliance" are required, the manufacturer shall furnish a certificate certifying that the indicators have been manufactured, tested, and conform to the requirements of this specification. The certificate shall show the production lot identification number, nominal size, ASTM designation and type, and purchase order number.

16. Responsibility

16.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser and certifies that the fastener was manufactured, sampled, tested and inspected in accordance with this specification and meets all of its requirements.

17. Product Marking

17.1 Each indicator shall be marked with a symbol identifying the manufacturer and type (see 1.2).

17.2 All markings shall be depressed on the same face of

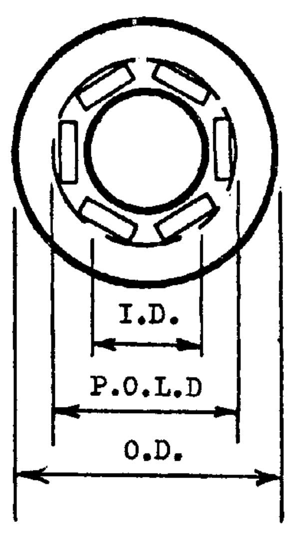

FIG. 3 Protrusion Outer Limit Diameter

the indicator as the protrusions. Raised markings are prohibited.

18. Packaging and Package Marking

18.1 *Packaging:*

18.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

18.1.2 Packaging shall be performed as soon as practical following final testing.

18.1.3 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

18.2 *Package Marking:*

18.2.1 Each shipping unit shall include or be plainly marked with the following information:

18.2.1.1 ASTM designation and type,

18.2.1.2 Size,

18.2.1.3 Name and brand or trademark of the manufacturer,

18.2.1.4 Number of pieces,

18.2.1.5 Purchase order number,

18.2.1.6 Name of product,

18.2.1.7 Lot identification number, and

18.2.1.8 Country of origin.

19. Storage

19.1 The indicators shall be stored in an environment that preserves the surface condition supplied by the manufacturer.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this specification that have been incorporated since the last issue. For the convenience of the user, Committee F 16 has highlighted those changes that may impact the use of this specification. This section may also include descriptions of the changes or reasons for the changes, or both.

(1) Added paragraph 18.1 Packaging in accordance with Practice D 3951 and paragraph 18.2 Package Marking.

AMERICAN NATIONAL STANDARD

Square and Hex Bolts and Screws Inch Series

ANSI B18.2.1 - 1981

(REVISION OF B18.2.1 — 1972)

Including Hex Cap Screws and Lag Screws

SECRETARIAT

SOCIETY OF AUTOMOTIVE ENGINEERS
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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AMERICAN NATIONAL STANDARD

SQUARE AND HEX BOLTS AND SCREWS INCH SERIES

1 Introductory Notes

1.1 Scope

1.1.1 This Standard is intended to cover the complete general and dimensional data for the various types of inch series square and hex bolts and screws recognized as American National Standard. Also included are appendixes covering thread runout sleeve gages, gaging procedure for checking bolt and screw straightness, grade markings for steel bolts and screws, formulas on which dimensional data are based, wrench openings for bolts and screws, and a specification to assist in identifying a product as being a screw or a bolt. It should be understood, however, that where questions arise concerning acceptance of product, the dimensions in the tables shall govern over recalculation by formula.

1.1.2 The inclusion of dimensional data in this Standard is not intended to imply that all of the products described herein are stock production sizes. Consumers are requested to consult with manufacturers concerning lists of stock production sizes.

1.2 Dimensions

All dimensions in this Standard are in inches, unless stated otherwise.

1.3 Options

Options, where specified, shall be at the discretion of the manufacturer unless otherwise agreed upon by the manufacturer and the purchaser.

1.4 Terminology

For definitions of terms relating to fasteners or component features thereof used in this Standard, refer to American National Standard, Glossary of Terms for Mechanical Fasteners, ANSI B18.12.

1.5 Related Standards

It should be noted that standards for square and hex nuts, machine screws and machine screw nuts, tapping screws, socket cap screws, round head bolts, and other related fasteners are published under separate cover as listed on the back sheet of this Standard.

1.6 Referenced Standards

Copies of referenced ASTM standards may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

Copies of referenced SAE standards may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.

2 General Data

2.1 Heads

2.1.1 Width Across Flats. The width across flats of head shall be the distance measured perpendicular to the axis of product, overall between two opposite sides of the head in accordance with the notes on respective dimensional tables.

2.1.2 Head Height. The head height shall be the overall distance measured parallel to the axis of product from the top of the head to the bearing surface and shall include the thickness of the washer face where provided.

2.2 Bolt or Screw Length

The bolt or screw length shall be the distance measured parallel to the axis of product from the bearing surface of the head to the extreme end of the bolt or screw, including point, if the product is pointed.

2.3 Threads

Threads on all products except lag screws shall be Unified Standard, Class 2A, of the series specified in the notes on respective dimensional tables as documented in American National Standard, Unified Inch Screw Threads (UN and UNR Thread Form) ANSI B1.1. For threads with additive finish, the maximum daimeter of Class 2A may be exceeded by the amount of the allowance; that is, the Class 2A maximum diameters apply to an unplated or uncoated part or to a part before plating or coating, whereas the basic diameters (Class 2A maximum diameters plus the allowance) apply to a part after plating or coating.

2.4 Body Diameter, Minimum

The minimum body diameter on products for which no minimum limits are shown in the dimensional tables shall not be less than the minimum pitch diameter of the thread.

2.5 Finish

Unless otherwise specified, bolts and screws shall be supplied with a natural (as processed) finish, unplated or uncoated.

2.6 Workmanship

Bolts and screws shall be free from burrs, seams, laps, loose scale, irregular surfaces, and any defects affecting their serviceability.

2.7 Designation

Bolts and screws shall be designated by the following data in the sequence shown: nominal size (fractional or decimal equivalent); threads per inch (omit for lag screws); product length (fractional or two-place decimal equivalent); product name; material, including specification where necessary; and protective finish, if required. See examples below:

3/8-16 x 1-1/2 Square Bolt, Steel, Zinc Plated

1/2-13 x Hex Cap Screw, SAE Grade 8 Steel

.75 x 5.00 Hex Lag Screw, Steel

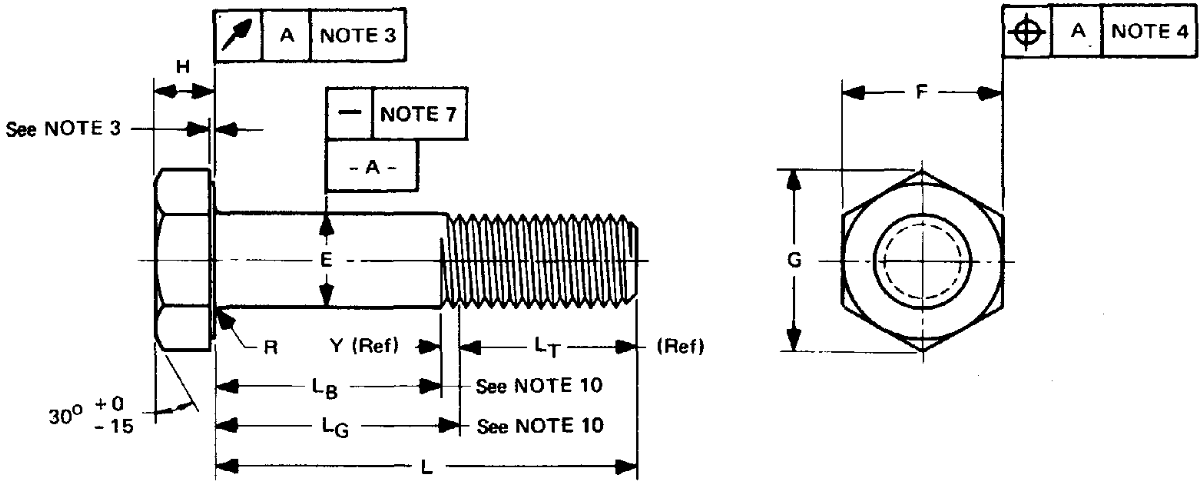


TABLE 5 DIMENSIONS OF HEAVY HEX STRUCTURAL BOLTS

Nominal Size or Basic Product Dia (15)		E Body Dia (5)		F Width Across Flats (2)			G Width Across Corners		H Height			R Radius of Fillet		L_T Thread Length (10)	Y Transition Thread Length (10)	Runout of Bearing Surface FIM (3)
		Max	Min	Basic	Max	Min	Max	Min	Basic	Max	Min	Max	Min	Basic	Max	Max
1/2	0.5000	0.515	0.482	7/8	0.875	0.850	1.010	0.969	5/16	0.323	0.302	0.031	0.009	1.00	0.19	0.016
5/8	0.6250	0.642	0.605	1 1/16	1.062	1.031	1.227	1.175	25/64	0.403	0.378	0.062	0.021	1.25	0.22	0.019
3/4	0.7500	0.768	0.729	1 1/4	1.250	1.212	1.443	1.383	15/32	0.483	0.455	0.062	0.021	1.38	0.25	0.022
7/8	0.8750	0.895	0.852	1 7/16	1.438	1.394	1.660	1.589	35/64	0.563	0.531	0.062	0.031	1.50	0.28	0.025
1	1.0000	1.022	0.976	1 5/8	1.625	1.575	1.876	1.796	39/64	0.627	0.591	0.093	0.062	1.75	0.31	0.028
1 1/8	1.1250	1.149	1.098	1 13/16	1.812	1.756	2.093	2.002	11/16	0.718	0.658	0.093	0.062	2.00	0.34	0.032
1 1/4	1.2500	1.277	1.223	2	2.000	1.938	2.309	2.209	25/32	0.813	0.749	0.093	0.062	2.00	0.38	0.035
1 3/8	1.3750	1.404	1.345	2 3/16	2.188	2.119	2.526	2.416	27/32	0.878	0.810	0.093	0.062	2.25	0.44	0.038
1 1/2	1.5000	1.531	1.470	2 3/8	2.375	2.300	2.742	2.622	15/16	0.974	0.902	0.093	0.062	2.25	0.44	0.041

Notes to Table 5:

Additional requirements in General Data on pp. 1 and 2.

(1) **Top of Head.** Top of head shall be full form and chamfered or rounded with the diameter of chamfer circle or start of rounding being equal to the maximum width across flats, within a tolerance of minus 15%.

(2) **Head Taper.** Maximum width across flats shall not be exceeded. No transverse section through the head between 25 and 75% of actual head height as measured from the bearing surface shall be less than the minimum width across flats.

(3) **Bearing Surface.** Bearing surface shall be flat and washer faced. Diameter of bearing surface shall be equal to the maximum width across flats within a tolerance of minus 10%.

Thickness of the washer face shall be not less than 0.015 in. nor greater than 0.025 in. for bolt sizes ¾ in. and smaller and not less than 0.015 in. nor greater than 0.035 in. for sizes larger than ¾ in.

The plane of the bearing surface shall be perpendicular to the axis of the body within the FIM limits specified. Measurement of FIM shall be made as close to the periphery of the bearing surface as possible while the bolt is being held in a collet or other gripping device at a distance of one bolt diameter from the underside of the head.

(4) **True Position of Head.** The axis of the head shall be located at true position with respect to the axis of the body (determined over a distance under the head equal to one diameter) within a tolerance zone having a diameter equivalent to 6% of the maximum width across flats, regardless of feature size.

(5) **Body Diameter.** There may be a reasonable swell or fin under the head, or die seam on the body not to exceed the basic bolt diameter by the following:

0.030 in. for sizes ½ in.
0.050 in. for sizes ⅝ and ¾ in.
0.060 in. for sizes over ¾ in. to 1¼ in.
0.090 in. for sizes over 1¼ in.

(6) **Point.** Point shall be chamfered or rounded at manufacturer's option. Length of point to first complete thread shall not exceed 1½ threads.

(7) **Straightness.** Shanks of bolts shall be straight within the following limits: for bolts with nominal lengths to and including 12 in. the maximum camber shall be 0.006 in. per inch of bolt length, and for bolts with nominal lengths over 12 in. to and including 24 in. the maximum camber shall be 0.008 in. per inch of length. A suggested gage and gaging procedure for checking bolt straightness is given in Appendix II.

(8) **Bolt Length.** Bolts are normally supplied in ¼ in. length increments, all lengths.

(9) **Length Tolerance.** Bolt length tolerances shall be as tabulated below:

Nominal Bolt Size	1/2	5/8	3/4 thru 1	1-1/8 thru 1-1/2
Nominal Bolt Length	Tolerance on Length			
Thru 6 in.	–0.12	–0.12	–0.19	–0.25
Over 6 in.	–0.19	–0.25	–0.25	–0.25

(10) **Thread Length.** The length of thread on bolts shall be controlled by the grip gaging length L_G max and body length L_B min as set forth in the following:

Grip gaging length L_G max is the distance measured parallel to the axis of bolt from the underhead bearing surface to the face of a non-counterbored or non-countersunk standard GO thread ring gage assembled by hand as far as the thread will permit. It shall be used as the criterion for inspection. The maximum grip gaging length, as calculated and rounded to two decimal places for any bolt not threaded full length, shall be equal to the nominal bolt length minus the basic thread length (L_G max = L nom - L_T). For bolts which are threaded full length, L_B max defines the unthreaded length under the head and shall not exceed the length of 2.5 times the thread pitch for sizes up to and including 1 in., and 3.5 times the thread pitch for sizes larger than 1 in. L_G max represents the minimum design grip length of the bolt and shall be used for determining thread availability when selecting bolt lengths even though usable threads may extend beyond this point.

Basic thread length L_T is a reference dimension, intended for calculation purposes only, which represents the distance from the extreme end of the bolt to the last complete (full form) thread.

Body length L_B min is the distance measured parallel to the axis of bolt from the underhead bearing surface to the last scratch of thread or to the top of the extrusion angle. It shall be used as a criterion for inspection. The minimum body length as calculated and rounded to two decimal places shall be equal to the maximum grip gaging length minus the maximum transition thread length ($L_B \min = L_G \max - Y \max$). Bolts of nominal lengths which have a calculated L_B min length equal to or shorter than 2.5 times the thread pitch for sizes 1 in. and smaller, and 3.5 times the thread pitch for sizes larger than 1 in. shall be threaded for full length.

Transition thread length Y is a reference dimension, intended for calculation purposes only, which represents the length of incomplete threads and tolerance on grip gaging length.

(11) **Incomplete Thread Diameter.** The major diameter of incomplete thread shall not exceed the actual major diameter of the full form thread.

(12) **Threads.** Threads, when rolled, shall be in the Unified Inch coarse or 8 thread series (UNRC or 8 UNR Series), Class 2A. Threads produced by other methods may be Unified Inch coarse or 8 thread series (UNC or 8 UN Series), Class 2A. Acceptability of screw threads shall be determined based on System 21, ANSI B1.3 Screw Thread Gaging Systems for Dimensional Acceptability.

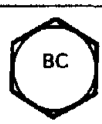
(13) **Identification Symbols.** Identification marking symbols on the tops of heads for bolt sizes 5/8 in. and smaller shall project not less than 0.005 in. above the surface nor more than 0.015 in. over the specified maximum head height. Bolt sizes larger than 5/8 in. shall project not less than the equivalent in inches of 0.0075 times the basic bolt diameter above the surface nor more than 0.030 in. over the specified maximum head height. ASTM grade markings for steel bolts are given in Appendix III.

(14) **Material.** Chemical and mechanical properties of steel bolts shall conform to ASTM A325 or ASTM A490 (see Appendix III).

(15) **Nominal Size.** Where specifying nominal size in decimals, zeros preceding the decimal and in the fourth decimal place shall be omitted.

APPENDIX III

ASTM AND SAE GRADE MARKINGS FOR STEEL BOLTS AND SCREWS

Grade Marking	Specification	Material
 NO MARK	SAE–Grade 1	Low or Medium Carbon Steel
	ASTM–A307	Low Carbon Steel
	SAE–Grade 2	Low or Medium Carbon Steel
	SAE–Grade 5	Medium Carbon Steel, Quenched and Tempered
	ASTM–A 449	
	SAE–Grade 5.2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM–A 325 Type 1	Medium Carbon Steel, Quenched and Tempered Radial dashes optional
	ASTM–A 325 Type 2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM–A 325 Type 3	Atmospheric Corrosion (Weathering) Steel, Quenched and Tempered
	ASTM–A 354 Grade BC	Alloy Steel, Quenched and Tempered
	SAE–Grade 7	Medium Carbon Alloy Steel, Quenched and Tempered, Roll Threaded After Heat Treatment
	SAE–Grade 8	Medium Carbon Alloy Steel, Quenched and Tempered
	ASTM–A 354 Grade BD	Alloy Steel, Quenched and Tempered
	SAE–Grade 8.2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM–A 490 Type 1	Alloy Steel, Quenched and Tempered
	ASTM–A 490 Type 3	Atmospheric Corrosion (Weathering) Steel, Quenched and Tempered

APPENDIX VI

SPECIFICATIONS FOR IDENTIFICATION OF BOLTS AND SCREWS

1 Scope

This specification establishes a recommended procedure for determining the identity of an externally threaded fastener as a bolt or as a screw.

2 Definitions

2.1 Bolt

A bolt is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by torquing a nut.

2.2 Screw

A screw is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by torquing the head.

3 Explanatory Data

A bolt is designed for assembly with a nut. A screw has features in its design which makes it capable of being used in a tapped or other preformed hole in the work. Because of basic design, it is possible to use certain types of screws in combination with a nut. Any externally threaded fastener which has a majority of the design characteristics which assist its proper use in a tapped or other preformed hole is a screw, regardless of how it is used in its service application.

4 Procedure

To identify an externally threaded fastener as a bolt or as a screw, two sets of criteria – Primary and Supplementary – shall be applied. The Primary Criteria (5.1 thru 5.4) shall be applied first. Any fastener which satisfies one of the Primary Criteria shall be identified accordingly, and no further examination need be made. The Supplementary Criteria (6.1 thru 6.9, and not listed in order of importance or priority of application) shall be applied to a fastener which does not satisfy completely any one of the Primary Criteria. The Supplementary Criteria detail the principal features in the design of an externally threaded fastener which contribute to its proper use as a screw. A fastener having a majority of these characteristics shall be identified as a screw.

5 Primary Criteria

5.1 An externally threaded fastener which, because of head design or other feature, is prevented from being turned during assembly, and which can be tightened or released only by torquing a nut, is a bolt. (Example: round head bolts, track bolts, plow bolts)

5.2 An externally threaded fastener which has a thread form which prohibits assembly with a nut having a straight thread of multiple pitch length, is a screw. (Example: wood screws, tapping screws)

5.3 An externally threaded fastener, which must be assembled with a nut to perform its intended service, is a bolt. (Example: heavy hex structural bolt)

5.4 An externally threaded fastener, which must be torqued by its head into a tapped or other preformed hole to perform its intended service, is a screw. (Example: square head set screw)

6 Supplementary Criteria

6.1 Under Head Fillet

A screw should have a controlled fillet at the junction of the head with the body. Because of the severe combined torsion and tension stresses at this junction when torquing the head, the minimum limits of the fillet radius should be specified. Because the screw must be capable of being turned through a minimum clearance hole and into an immovable tapped hole, the maximum limits of the fillet radius should be specified to assure solid seating of the head, and to prevent interference at the top of the hole with the junction of head to body.

6.2 Bearing Surface

The under head bearing surface of a screw should be smooth and flat to minimize frictional resistance during tightening, to prevent scoring of the surface against which the head is turned, and to produce uniform clamping loads.

6.3 Head Angularity

The angularity (squareness) of the under head bearing surface with the shank of a screw should be controlled to minimize eccentric loading in the screw or assembled parts, and to assure complete seating and uniform under head bearing pressure.

6.4 Body

The body of a screw should be closely controlled in accuracy of size and roundness. To fit effectively through a minimum clearance hole, the body diameter must have close tolerances, preferably unilateral on the minus side.

6.5 Shank Straightness

The shank of a screw should be particularly straight to permit ready engagement with the internal thread, to prevent eccentric loading in the fastener or in the assembled parts, and to minimize interference with the walls of a minimum clearance hole.

6.6 Thread Concentricity

The threads of a screw should be concentric with the body axis within close limits to permit assembly into a tapped hole (which usually has a length of thread engagement longer than a nut) without binding of the body against the walls of a minimum clearance hole.

6.7 Thread Length

The length of thread on a screw must be sufficient to develop the full strength of the fastener in tapped holes in various materials.

6.8 Point

A screw should have a chamfered, or other specially prepared point at its end to facilitate entry into the hole and easy start with the internal thread, which may be distant from the top of the hole. The point also protects the first thread, which, if damaged, may gall or scar the internal thread throughout its entire length.

6.9 Length

The length of a screw should be closely toleranced, with variance preferably unilateral on the minus side to prevent bottoming of the fastener in a tapped hole.

AN AMERICAN NATIONAL STANDARD

Square and Hex Nuts (Inch Series)

ASME/ANSI B18.2.2-1987

[REVISION OF ANSI B18.2.2-1972(R1983)]

SPONSORED AND PUBLISHED BY

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This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda or written interpretations of the requirements of this Standard issued to this edition.

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SQUARE AND HEX NUTS (INCH SERIES)

1 INTRODUCTORY NOTES

1.1 Scope

1.1.1 This Standard is intended to cover the complete general and dimensional data for the various types of inch series square and hex nuts recognized as "American National Standard." Also included are appendices covering gaging of slots in slotted nuts, wrench openings for nuts, and formulas on which dimensional data are based. It should be understood, however, that where questions arise concerning acceptance of product, the dimensions in the Tables shall govern over recalculation by formula.

1.1.2 The inclusion of dimensional data in this Standard is not intended to imply that all of the products described herein are stock production sizes. Consumers are requested to consult with manufacturers concerning lists of stock production sizes.

1.2 Dimensions

All dimensions in this Standard are in inches, unless stated otherwise.

1.3 Options

Options, where specified, shall be at the discretion of the manufacturer unless otherwise agreed upon by the manufacturer and the purchaser.

1.4 Terminology

For definitions of terms relating to fasteners or component features thereof used in this standard, refer to ANSI B18.12, Glossary of Terms for Mechanical Fasteners.

1.5 Referenced Standards

Copies of referenced ASTM standards may be obtained from ASTM, 1916 Race Street, Philadelphia, Pennsylvania 19103.

Copies of referenced SAE standards may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096

2 GENERAL DATA

2.1 Width Across Flats

The width across flats of nut shall be the distance measured, perpendicular to the axis of nut, overall between two opposite sides of the nut in accordance with the notes on respective dimensional tables. For milled-from-bar hex nuts, the nominal bar size used shall be the closest commercially available size to the specified basic width across flats of the nut. For milled-from-bar nonferrous nuts, the tabulated maximum (basic) width across flats dimensions may be exceeded to conform with the commercial tolerances of drawn or rolled bar stock material.

2.2 Nut Thickness

The nut thickness shall be the overall distance, measured parallel to the axis of nut, from the top of the nut to the bearing surface and shall include the thickness of the washer face where provided.

2.3 Threads

Threads shall be Unified Standard, Class 2B, of the series specified in the notes on respective dimensional tables, in accordance with Unified Inch Screw Threads (UN and UNR Thread Form), ANSI B1.1.

2.3.1 Thread Gaging. Unless otherwise specified by the purchaser, gaging for screw thread dimensional acceptability shall be in accordance with Gaging System 21 as specified in ANSI/ASME B1.3M, Screw Thread Gaging Systems for Dimensional Acceptability.

2.4 Finish

Unless otherwise specified, nuts shall be supplied with a natural (as-processed) finish, unplated or uncoated.

2.5 Workmanship

Nuts shall be free from burrs, seams, laps, loose scale, irregular surfaces, and any defects affecting their serviceability.

2.6 Designation

Nuts shall be designated by the following data in the sequence shown: nominal size (fraction or decimal); threads per inch; product name; material (including specification, where necessary); protective finish, if required.

EXAMPLES:

1/2 — 13 Square Nut, Steel, Zinc Plated

3/4 — 16 Hex Nut, SAE J995 Grade 5, Steel

1.000 — 8 Hex Thick Slotted Nut, ASTM F594
(Alloy Group 1) Corrosion Resistant Steel

TABLE 9

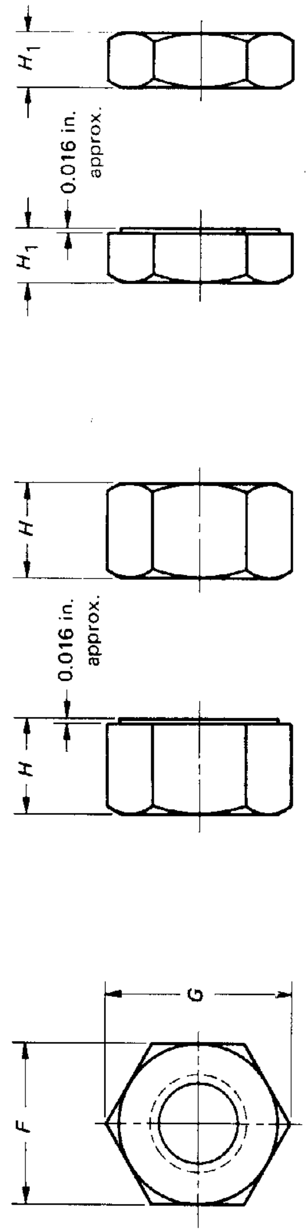

TABLE 9 DIMENSIONS OF HEAVY HEX NUTS AND HEAVY HEX JAM NUTS

Nominal Size or Basic Major Diam. of Thread		*F* Width Across Flats			*G* Width Across Corners		*H* Thickness Heavy Hex Nuts			*H*$_1$ Thickness Heavy Hex Jam Nuts			Runout of Bearing Face FIM: Heavy Hex Nuts, Specified Proof Load, Up to 150,000 psi	Runout of Bearing Face FIM: Heavy Hex Nuts, Specified Proof Load, 150,000 psi and Greater	Runout of Bearing Face FIM: Heavy Hex Jam Nuts, All Strength Levels
		Basic	Max.	Min.	Max.	Min.	Basic	Max.	Min.	Basic	Max.	Min.	Max.	Max.	Max.
1/4	0.2500	1/2	0.500	0.488	0.577	0.556	15/64	0.250	0.218	11/64	0.188	0.156	0.017	0.011	0.017
5/16	0.3125	9/16	0.562	0.546	0.650	0.622	19/64	0.314	0.280	13/64	0.220	0.186	0.020	0.012	0.020
3/8	0.3750	11/16	0.688	0.669	0.794	0.763	23/64	0.377	0.341	15/64	0.252	0.216	0.021	0.014	0.021
7/16	0.4375	3/4	0.750	0.728	0.866	0.830	27/64	0.441	0.403	17/64	0.285	0.247	0.022	0.015	0.022
1/2	**0.5000**	7/8	**0.875**	**0.850**	**1.010**	**0.969**	31/64	**0.504**	**0.464**	19/64	**0.317**	**0.277**	0.023	0.016	0.023
9/16	0.5625	15/16	0.938	0.909	1.083	1.037	35/64	0.568	0.526	21/64	0.349	0.307	0.024	0.017	0.024
5/8	**0.6250**	**1 1/16**	**1.062**	**1.031**	**1.227**	**1.175**	39/64	**0.631**	**0.587**	23/64	**0.381**	**0.337**	0.025	0.018	0.025
3/4	**0.7500**	**1 1/4**	**1.250**	**1.212**	**1.443**	**1.382**	47/64	**0.758**	**0.710**	27/64	**0.446**	**0.398**	0.027	0.020	0.027
7/8	**0.8750**	**1 7/16**	**1.438**	**1.394**	**1.660**	**1.589**	55/64	**0.885**	**0.833**	31/64	**0.510**	**0.458**	0.029	0.022	0.029
1	**1.0000**	**1 5/8**	**1.625**	**1.575**	**1.876**	**1.796**	63/64	**1.012**	**0.956**	35/64	**0.575**	**0.519**	0.031	0.024	0.031
1 1/8	**1.1250**	**1 13/16**	**1.812**	**1.756**	**2.093**	**2.002**	**1 7/64**	**1.139**	**1.079**	39/64	**0.639**	**0.579**	0.033	0.027	0.033
1 1/4	**1.2500**	**2**	**2.000**	**1.938**	**2.309**	**2.209**	**1 7/32**	**1.251**	**1.187**	23/32	**0.751**	**0.687**	0.035	0.030	0.035
1 3/8	**1.3750**	**2 3/16**	**2.188**	**2.119**	**2.526**	**2.416**	**1 11/32**	**1.378**	**1.310**	25/32	**0.815**	**0.747**	0.038	0.033	0.038
1 1/2	**1.5000**	**2 3/8**	**2.375**	**2.300**	**2.742**	**2.622**	**1 15/32**	**1.505**	**1.433**	27/32	**0.880**	**0.808**	0.041	0.036	0.041
1 5/8	1.6250	2 9/16	2.562	2.481	2.959	2.828	1 19/32	1.632	1.556	29/32	0.944	0.868	0.044	0.038	0.044
1 3/4	**1.7500**	**2 3/4**	**2.750**	**2.662**	**3.175**	**3.035**	**1 23/32**	**1.759**	**1.679**	31/32	**1.009**	**0.929**	0.048	0.041	0.048
1 7/8	1.8750	2 15/16	2.938	2.844	3.392	3.242	1 27/32	1.886	1.802	1 1/32	1.073	0.989	0.051	0.044	0.051
2	**2.0000**	**3 1/8**	**3.125**	**3.025**	**3.608**	**3.449**	**1 31/32**	**2.013**	**1.925**	**1 3/32**	**1.138**	**1.050**	0.055	0.047	0.055
2 1/4	2.2500	3 1/2	3.500	3.388	4.041	3.862	2 13/64	2.251	2.155	1 13/64	1.251	1.155	0.061	0.052	0.061
2 1/2	2.5000	3 7/8	3.875	3.750	4.474	4.275	2 29/64	2.505	2.401	1 29/64	1.505	1.401	0.068	0.058	0.068
2 3/4	2.7500	4 1/4	4.250	4.112	4.907	4.688	2 45/64	2.759	2.647	1 37/64	1.634	1.522	0.071	0.064	0.074
3	3.0000	4 5/8	4.625	4.475	5.340	5.102	2 61/64	3.013	2.893	1 45/64	1.763	1.643	0.081	0.070	0.081
3 1/4	3.2500	5	5.000	4.838	5.774	5.515	3 3/16	3.252	3.124	1 13/16	1.876	1.748	0.087	0.075	0.087
3 1/2	3.5000	5 3/8	5.375	5.200	6.207	5.928	3 7/16	3.506	3.370	1 15/16	2.006	1.870	0.094	0.081	0.094
3 3/4	3.7500	5 3/4	5.750	5.562	6.640	6.341	3 11/16	3.760	3.616	2 1/16	2.134	1.990	0.100	0.087	0.100
4	4.0000	6 1/8	6.125	5.925	7.073	6.755	3 15/16	4.014	3.862	2 3/16	2.264	2.112	0.107	0.093	0.107
See Notes			1		2									3	

(For additional requirements refer to Notes on p. 22 and General Data on pp. 1 and 2.)

TABLE 9 (CONT'D)

GENERAL NOTES:

(a) Unification. Bold type indicates products unified dimensionally with British and Canadian standards. Unification of fine thread products is limited to sizes 1 in. and under.

(b) True Position of Tapped Hole. The axis of tapped hole shall be located at true position with respect to the axis of nut body within a tolerance zone having a diameter equivalent to 4% of the maximum width across flats for 1 ½ in. nominal size nuts or smaller, and 6% of the maximum width across flats for nuts larger than 1 ½ in., regardless of feature size.

(c) Countersink. Tapped hole shall be countersunk on the bearing face or faces. The maximum countersink diameter shall be the thread basic (nominal) major diameter plus 0.030 in. for ³⁄₈ in. nominal size nuts and smaller, and 1.08 times the basic major diameter for nuts larger than ³⁄₈ in. No part of the threaded portion shall project beyond the bearing surface.

(d) Threads. Threads shall be unified coarse, fine, or 8 thread series (UNC, UNF or 8 UN series), Class 2B. Unless otherwise specified, coarse thread series shall be furnished.

(e) Material. Unless otherwise specified, chemical and mechanical properties of steel nuts shall conform with Grade A of ASTM A 563, Carbon and Alloy Steel Nuts; or Grade 2 of SAE J995, Mechanical and Material Requirements for Steel Nuts. Nuts of other materials such as corrosion resistant (stainless) steel, brass, bronze, and aluminum alloys shall have properties as agreed upon between the manufacturer and purchaser. The properties for nuts of several grades of corrosion resistant steel alloys are covered in ASTM F 594, and of several nonferrous materials in the ASTM F 467.

NOTES:

(1) Width Across Flats. Maximum width across flats shall not be exceeded (see exception in General Data). No transverse action through the nut between 25% and 75% of the actual nut thickness as measured from the bearing surface shall be less than the minimum width across flats. For milled-from-bar nuts, see statement in General Data pertaining to the nominal bar size to be used.

(2) Corner Fill. A rounding or lack of fill at junction of hex corners with chamfer shall be permissible provided the width across corners is within specified limits at and beyond a distance equal to 17.5% of the basic thread diameter from the chamfered faces.

(3) Tops and Bearing Surfaces of Nuts. Nuts in sizes ⁷⁄₁₆ in. nominal size and smaller shall be double chamfered. Larger size nuts shall be double chamfered or have washer faced bearing surface and chamfered top.

The diameter of chamfer circle on double chamfered nuts and diameter of washer face shall be within the limits of the maximum width across flats and 95% of the minimum width across flats.

The tops of washer faced nuts shall be flat and the diameter of chamfer circle shall be equal to the maximum width across flats within a tolerance of − 15%. The length of chamfer at hex corners shall be from 5% to 15% of the basic thread diameter. The surface of chamfer may be slightly convex or rounded.

Bearing surfaces shall be flat and, unless otherwise specified, shall be perpendicular to the axis of the threaded hole within the FIM limits tabulated for the respective nut size, type, and strength level. Where purchaser specifies close runout of bearing face style heavy hex or heavy hex jam nuts in nominal sizes 2 in. through 4 in., nuts shall be so processed as to have a maximum bearing face runout of 0.010 in. FIM.

APPENDIX E

AASHTO Standard Specifications for Highway Bridges--Division II

Section 11

STEEL STRUCTURES

11.1 GENERAL

11.1.1 Description

This work shall consist of furnishing, fabricating, and erecting steel structures and structural steel portions of other structures in accordance with these Specifications, the Special Provisions and the details shown on the plans.

The structural steel fabricating plant shall be certified under the AISC Quality Certification Program ~~or equivalent program.~~

Details of design which are permitted to be selected by the contractor shall conform to Division I of these specifications.

Painting shall conform to the provisions of Section 13 of these specifications.

Falsework used in the erection of structural steel shall conform to the provisions of Section 3 of these specifications.

Structural components designated on the plans or in the special provisions as "fracture critical" shall conform to the provisions of the AASHTO Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members.

Welding and weld qualification tests shall conform to the provisions of the ANSI/AASHTO/AWS Bridge Welding Code D1.5.

11.1.2 Notice of Beginning of Work

The Contractor shall give the Engineer ample notice of the beginning of work at the mill or in the shop, so that inspection may be provided. The term "mill" means any rolling mill or foundry where material for the work is to be manufactured. No material shall be manufactured, or work done in the shop, before the Engineer has been so notified.

11.1.3 Inspection

Structural steel will be inspected at the fabrication site.

The Contractor shall furnish to the Engineer a copy of all mill orders and certified mill test reports. Mill test reports shall show the chemical analysis and physical test results for each heat of steel used in the work.

With the approval of the Engineer, certificates of compliance shall be furnished in lieu of mill test reports for material that normally is not supplied with mill test reports, and for items such as fills, minor gusset plates and similar material when quantities are small and the material is taken from stock.

Certified mill test reports for steels with specified impact values shall include, in addition to other test results, the results of Charpy V-notch impact tests. When fine grain practice is specified, the test report shall confirm that the material was so produced. Copies of mill orders shall be furnished at the time orders are placed with the manufacturer. Certified mill test reports and Certificates of Compliance shall be furnished prior to the start of fabrication of material covered by these reports. The Certificate of Compliance shall be signed by the manufacturer and shall certify that the material is in conformance with the specifications to which it has been manufactured.

Material to be used shall be made available to the Engineer so that each piece can be examined. The Engineer shall have free access at all times to any portion of the fabrication site where the material is stored or where work on the material is being performed.

11.1.4 Inspector's Authority

The Inspector shall have the authority to reject materials or workmanship which do not fulfill the requirements of these Specifications. In cases of dispute, the Contractor may appeal to the Engineer, whose decision shall be final.

~~equivalent program.~~ Category I. The fabrication of fracture critical members shall be Category III.

Inspection at the mill and shop is intended as a means of facilitating the work and avoiding errors, and it is expressly understood that it will not relieve the Contractor of any responsibility in regard to defective material or workmanship and the necessity for replacing the same.

The acceptance of any material or finished members by the Inspector shall not be a bar to their subsequent rejection, if found defective. Rejected materials and workmanship shall be replaced as soon as practical or corrected by the Contractor.

11.2 WORKING DRAWINGS

The Contractor shall expressly understand that the Engineer's approval of the working drawings submitted by the Contractor covers the requirements for "strength and detail," and that the Engineer assumes no responsibility for errors in dimensions.

Working drawings must be approved by the Engineer prior to performance of the work involved and such approval shall not relieve the Contractor of any responsibility under the contract for the successful completion of the work.

11.2.1 Shop Drawings

The Contractor shall submit copies of the detailed shop drawings to the Engineer for approval. Working drawings shall be submitted sufficiently in advance of the start of the affected work to allow time for review by the Engineer and corrections by the Contractor without delaying the work.

Working drawings for steel structures shall give full detailed dimensions and sizes of component parts of the structure and details of all miscellaneous parts, such as pins, nuts, bolts, drains, etc.

Where specific orientation of plates is required, the direction of rolling of plates shall be shown.

Working drawings shall specifically identify each piece that is to be made of steel which is to be other than AASHTO M 270 (ASTM A709) Grade 36 steel.

11.2.2 Erection Drawings

The Contractor shall submit drawings illustrating fully his proposed method of erection. The drawings shall show details of all falsework bents, bracing, guys, dead-men, lifting devices, and attachments to the bridge members: sequence of erection, location of cranes and barges, crane capacities, location of lifting points on the bridge members, and weights of the members. The plan and drawings shall be complete in detail for all anticipated phases and conditions during erection. Calculations may be required to demonstrate that allowable stresses are not exceeded and that member capacities and final geometry will be correct.

11.2.3 Camber Diagram

A camber diagram shall be furnished to the Engineer by the Fabricator, showing the camber at each panel point in the cases of trusses or arch ribs, and at the location of field splices and fractions of span length (1/4 points minimum) in the cases of continuous beam and girders or rigid frames. The camber diagram shall show calculated cambers to be used in preassembly of the structure in accordance with Article 11.5.3.

11.3 MATERIALS

11.3.1 Structural Steel

11.3.1.1 General

Steel shall be furnished according to the following specifications. The grade or grades of steel to be furnished shall be as shown on the plans or specified. If not so shown or specified, structural carbon steel shall be furnished. When copper bearing steel is specified, the steel shall contain not less than 0.2 percent copper.

All steel for use in main load-carrying member components subject to tensile stress shall conform to the applicable Charpy V-Notch Impact Test requirements of AASHTO M270 (ASTM A709).

11.3.1.2 Carbon Steel

Unless otherwise specified, structural carbon steel for bolted or welded construction shall conform to: Structural Steel for Bridges, AASHTO M270 (ASTM A709) Grade 36.

11.3.1.3 High-Strength Low-Alloy Structural Steel

High-strength low-alloy steel shall conform to:

Structural Steel for Bridges, AASHTO M270 (ASTM A709) Grades 50 or 50W.

11.3.1.4 High-Strength Low-Alloy, Quenched and Tempered Structural Steel Plate

High-strength, low-alloy quenched and tempered steel plate shall conform to AASHTO M270 (ASTM A709) Grade 70W.

11.3.1.5 High-Yield-Strength, Quenched and Tempered Alloy Steel Plate

High-yield-strength, quenched, and tempered alloy steel plate shall conform to:

(a) Structural Steel for Bridges AASHTO M270 (ASTM A709) Grades 100 or 100W.
(b) Quenched and tempered alloy steel structural shapes and seamless mechanical tubing, meeting all of the mechanical and chemical requirements of A709 Grades 100 or 100W steel, except that the specified maximum tensile strength may be 140,000 psi for structural shapes and 145,000 psi for seamless mechanical tubing, shall be considered as A709 Grades 100 and 100W steel.

11.3.1.6 Eyebars

Steel for eyebars shall be of a weldable grade. These grades include structural steel conforming to:

(a) Structural Steel for Bridges, AASHTO M270 (ASTM A709) Grade 36.
(b) Structural Steel for Bridges AASHTO M270 (ASTM A709) Grades 50 and 50W.

11.3.1.7 Structural Tubing

Structural tubing shall be either cold-formed welded or seamless tubing conforming to ASTM 500, Grade B or hot-formed welded or seamless tubing conforming to ASTM 501.

11.3.2 High-Strength Fasteners

11.3.2.1 Material

High-strength bolts for structural steel joints including suitable nuts and plain hardened washers shall conform to either AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490). When high-strength bolts are used with unpainted weathering grades of steel, the bolts shall be Type 3.

The supplier shall provide a lot number appearing on the shipping package and a certification noting when and where all testing was done, including rotational capacity tests, and zinc thickness when galvanized bolts and nuts are used.

The maximum hardness for AASHTO M164 (ASTM A325) bolts 1" or less in diameter shall be 33 HRC. The maximum tensile strength shall be 150 ksi for bolts 1" or less in diameter and 120 ksi for larger bolts.

Proof load tests (ASTM F606 Method 1) are required for the bolts. Wedge tests of full size bolts are required in accordance with Section 8.3 of AASHTO M164. Galvanized bolts shall be wedge tested after galvanizing. Proof load tests (AASHTO M291) are required for the nuts. The proof load tests for nuts to be used with galvanized bolts shall be performed after galvanizing, over-tapping and lubricating.

Nuts for AASHTO M164 (ASTM A325) bolts shall conform to AASHTO M291 (ASTM A563) or AASHTO M292 (ASTM A194). Nuts for AASHTO M253 (ASTM A490) bolts shall conform to the requirements of AASHTO M292 (ASTM A194). The permissable grades of nuts shall be as specified in AASHTO M164 (ASTM A325) and in AASHTO M253 (ASTM A490).

All galvanized nuts shall be lubricated with a lubricant containing a visible dye. Black bolts must be oily when installed.

11.3.2.2 Identifying Marks

AASHTO M164 (ASTM A325) for bolts and the specifications referenced therein for nuts require that bolts and nuts manufactured to the specification be identified by specific markings on the top of the bolt head and on one face of the nut. Head markings must identify the strength grade by the symbol "A325," the manufacturer and the type. Nut markings must identify the strength grade, the manufacturer, and, if Type 3, the type.

AASHTO M253 (ASTM A490) for bolts and the specifications referenced therein for nuts require that bolts and nuts manufactured to the specifications be identified by specific markings on the top of the bolt head and on one face of the nut. Head markings must identify the strength grade by the symbol "A490," the manufacturer and the type. Nut markings must identify the strength grade, the manufacturer and, if Type 3, the type.

Washer markings must identify the manufacturer and, if Type 3, the type.

11.3.2.3 Dimensions

Bolt and nut dimensions shall conform to the requirements for Heavy Hexagon Structural Bolts and for Heavy Semi-Finished Hexagon Nuts given in ANSI Standard B18.2.1 and B18.2.2, respectively.

11.3.2.4 Galvanized High-Strength Fasteners

When fasteners are specified to be galvanized, they shall be hot-dip galavanized in accordance with AASHTO M232 (ASTM A153) or, when approved by the Engineer, fasteners may be mechanically galvanized to an equal thickness in accordance with AASHTO M298 (ASTM B695). Bolts to be galvanized shall be either AASHTO M164 (ASTM A325) Type 1 or Type 2. If Type 2 bolts are galvanized by the hot-dip galvanizing process, they shall be tension tested after galvanizing as required by AASHTO M164 (ASTM A325). Nuts and bolts of any nut/bolt assembly shall be galvanized by the same process. The nuts should be overtapped to the minimum amount required for the fastener assembly, and shall be lubricated with a lubricant containing a visible dye so a visual check can be made for the lubricant at the time of field installation. Galvanized nuts and bolts are to be treated as an assembly and shipped together. AASHTO M253 (ASTM A490) bolts shall not be hot-dip galvanized.

11.3.2.5 Washers

Washers shall be hardened steel washers conforming to the requirements of AASHTO M293 (ASTM F436) and Article 11.5.6.4.3.

11.3.2.6 Alternative Fasteners

Other fasteners or fastener assemblies which meet the materials, manufacturing, and chemical composition requirements of AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490), and which meet the mechanical property requirements of the same specification in full-size tests, and which have body diameter and bearing areas under the head and nut, or their equivalent, not less than those provided by a bolt and nut of the same nominal dimensions prescribed in Art. 11.3.2.3, may be used, subject to the approval of the Engineer. Such alternate fasteners may differ in other dimensions from those of the specified bolts and nuts.

Subject to the approval of the Engineer, high-strength steel lock-pin and collar fasteners may be used as an alternate for high strength bolts as shown on the plans. The shank and head of high-strength steel lock-pin and collar fasteners shall meet the requirements of Art. 11.3.2.3. Each fastener shall provide a solid shank body of sufficient diameter to provide tensile and shear strength equivalent to or greater than the bolt specified, shall have a cold forged head on one end, of type and dimensions as approved by the Engineer, a shank length suitable for material thickness fastened, locking grooves, breakneck groove and pull grooves (all annular grooves) on the opposite end. Each fastener shall provide a steel locking collar of proper size for shank diameter used which, by means of suitable installation tools, is cold swaged into the locking grooves forming head for the grooved end of the fastener after the pull groove section has been removed. The steel locking collar shall be a standard product of an established manufacturer of lock-pin and collar fasteners, as approved by the Engineer.

11.3.2.7 Load Indicator Devices

Load indicating devices may be used in conjunction with bolts, nuts and washers specified in Article 11.3.2.1. Load indicating devices shall conform to the requirements of ASTM Specification for Compressible-Washer Type Direct Tension Indicators For Use with Structural Fasteners, ASTM F959, except as provided in the following paragraph.

Subject to the approval of the Engineer, alternate design direct tension indicating devices may be used provided they satisfy the requirements of Article 11.5.6.4.6 or other requirements detailed in supplemental specifications provided by the manufacturer and subject to the approval of the Engineer.

11.3.3 Welded Stud Shear Connectors

11.3.3.1 Materials

Shear connector studs shall conform to the requirements of Cold Finished-Carbon Steel Bars and Shafting, AASHTO M169 (ASTM A108), cold drawn bars, grades 1015, 1018, or 1020, either semi- or fully-killed. If flux retaining caps are used, the steel for the caps shall be of a low carbon grade suitable for welding and shall comply with Cold-Rolled Carbon Steel Strip, ASTM A109.

Tensile properties as determined by tests of bar stock after drawing or of finished studs shall conform to the following requirements:

Tensile Strength	60,000 psi (min.)
Yield Strength*	50,000 psi (min.)
Elongation	20% in 2 inches (min.)
Reduction of area	50% (min.)

*As determined by a 0.2% offset method.

11.3.3.2 Test Methods

Tensile properties shall be determined in accordance with the applicable sections of ASTM A370. Mechanical Testing of Steel Products. Tensile tests of finished studs shall be made on studs welded to test plates using a test fixture similar to that shown in Figure 7.2 of ANSI/AASHTO/AWS Bridge Welding Code D1.5. If fracture occurs outside of the middle half of the gage length, the test shall be repeated.

11.3.3.3 Finish

Finished studs shall be of uniform quality and condition, free from injurious laps, fins, seams, cracks, twists, bends, or other injurious defects. Finish shall be as produced by cold drawing, cold rolling, or machining.

11.3.3.4 Certification

The manufacturer shall certify that the studs as delivered are in accordance with the material requirements of this section. Certified copies of in-plant quality control test reports shall be furnished to the Engineer upon request.

11.3.3.5 Check Samples

The Engineer may select, at the Contractor's expense, studs of each type and size used under the contract, as necessary for checking the requirements of this section.

11.3.4 Steel Forgings and Steel Shafting

11.3.4.1 Steel Forgings

Steel forgings shall conform to the Specifications for Steel Forgings Carbon and Alloy for General Use, AASHTO M102 (ASTM A668), Classes C, D, F, or G.

11.3.4.2 Cold Finished Carbon Steel Shafting

Cold finished carbon steel shafting shall conform to the specifications for Cold Finished Carbon Steel Bars Standard Quality, AASHTO M169 (ASTM A108). Grade 10160-10300, inclusive, shall be furnished unless otherwise specified.

11.3.5 Steel Castings

11.3.5.1 Mild Steel Castings

Steel castings for use in highway bridge components shall conform to Standard Specifications for Steel Castings for Highway Bridges, AASHTO M192 (ASTM A486) or Carbon-Steel Castings for General Applications AASHTO M103 (ASTM A27). The class 70 or grade 70-36 of steel, respectively, shall be used unless otherwise specified.

11.3.5.2 Chromium Alloy-Steel Castings

Chromium alloy-steel castings shall conform to the Specification for Corrosion-Resistant Iron-Chromium, Iron-Chromium-Nickel and Nickel-Based Alloy Castings for General Application, AASHTO M163 (ASTM A743). Grade CA 15 shall be furnished unless otherwise specified.

11.3.6 Iron Castings

11.3.6.1 Materials

(1) Gray Iron Castings - Gray iron castings shall conform to the Specification for Gray Iron Castings, AASHTO M105 (ASTM A48), Class No. 30 unless otherwise specified.

(2) Ductile Iron Castings - Ductile iron castings shall conform to the Specifications for Ductile Iron Castings, ASTM A536, Grade 60-40-18 unless otherwise specified. In addition to the specified test coupons, test specimens from parts integral with the castings, such as risers, shall be tested for castings weighing more than 1,000 pounds to determine that the required quality is obtained in the castings in the finished condition.

(3) Malleable Castings - Malleable castings shall conform to the Specification for Malleable Iron Castings, ASTM A47. Grade No. 35018 shall be furnished unless otherwise specified.

11.3.6.2 Workmanship and Finish

Iron castings shall be true to pattern in form and dimensions, free from pouring faults, sponginess, cracks, blow holes, and other defects in positions affecting their strength and value for the service intended.

Castings shall be boldly filleted at angles and the arrises shall be sharp and perfect.

11.3.6.3 Cleaning

All castings must be sandblasted or otherwise effectively cleaned of scale and sand so as to present a smooth, clean, and uniform surface.

11.3.7 Galvanizing

When galvanizing is shown on the plans or specified in the special provisions, ferrous metal products, other than fasteners, shall be galvanized in accordance with the Specifications for Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shape Plates, Bars, and Strip, AASHTO M111 (ASTM A123).

11.4 FABRICATION

11.4.1 Identification of Steels During Fabrication

The Contractor's system of assembly-marking individual pieces, and the issuance of cutting instructions to the shop (generally by cross-referencing of the assembly-marks shown on the shop drawings with the corresponding item covered on the mill purchase order) shall be such as to maintain identity of the original piece.

The Contractor may furnish from stock, material that he can identify by heat number and mill test report.

During fabrication, up to the point of assembling members, each piece of steel, other than Grade 36 steel, shall show clearly and legibly its specification. This may be done by writing the material specification on the piece or using the identification color code shown in Table 11.4.

TABLE 11.4 Identification Color Codes

Grade 50	Green & Yellow
Grade 50W	Blue & Yellow
Grade 70W	Blue & Orange
Grade 100	Red
Grade 100W	Red & Orange

Other steels, except Grade 36 steel, not covered above, nor included in the AASHTO M160 (ASTM A6) Specification, shall have an individual color code which shall be established and kept on record for the Engineer.

Pieces of steel, other than Grade 36 steel, which prior to assembling into members, will be subject to fabricating operations such as blast cleaning, galvanizing, heating for forming, or painting which might obliterate paint color code marking, shall be marked for grade by steel die stamping or by a substantial tag firmly attached. Steel die stamps shall be low stress-type.

Upon request, the Contractor shall furnish an affidavit certifying that throughout the fabrication operation he has maintained the identification of steel in accordance with this specification.

11.4.2 Storage of Materials

Structural material, either plain or fabricated, shall be stored above the ground on platforms, skids, or other supports. It shall be kept free from dirt, grease, and other foreign matter, and shall be protected as far as practicable from corrosion.

11.4.3 Plates

11.4.3.1 Direction of Rolling

Unless otherwise shown on the plans, steel plates for main members and splice plates for flanges and main tension members, not secondary members, shall be cut and fabricated so that the primary direction of rolling is parallel to the direction of the main tensile and/or compressive stresses.

11.4.3.2 Plate Cut Edges

11.4.3.2.1 Edge Planing

Sheared edges of plate more than 5/8 inch in thickness and carrying calculated stress shall be planed, milled, ground, or thermal cut to a depth of 1/4 inch.

11.4.3.2.2 Oxygen Cutting

Oxygen cutting of structural steel shall conform to the requirements of the current edition of the ANSI/AASHTO/AWS Bridge Welding Code D1.5.

11.4.3.2.3 Visual Inspection and Repair of Plate Cut Edges

Visual inspection and repair of plate cut edges shall be in accordance with the ANSI/AASHTO/AWS Bridge Welding Code D1.5.

11.4.3.3 Bent Plates

11.4.3.3.1 General

Unwelded, load-carrying, rolled-steel plates to be bent shall conform to the following:

They shall be so taken from the stock plates that the bend line will be at right angles to the direction of rolling, except that cold-bent ribs for orthotropic-deck bridges may be bent with bend lines in the direction of rolling.

Before bending, the corners of the plates shall be rounded to a radius of 1/16 inch throughout the portion of the plate at which the bending is to occur.

11.4.3.3.2 Cold Bending

Cold bending shall be such that no cracking of the plate occurs. Minimum bend radii, measured to the concave face of the metal, are given in the following table:

Thickness in Inches (t)	Up to 1/2	Over 1/2 to 1	Over 1 to 1-1/2	Over 1-1/2 to 2-1/2	Over 2-1/2 to 4
Bend radii for all grades of structural steel in this specification	2t	2-1/2t	3t	3-1/2t	4t

Allowance for springback of Grades 100 and 100W steels should be about 3 times that for Grade 36 steel. For break press forming, the lower die span should be at least 16 times the plate thickness. Multiple hits are advisable.

11.4.3.3.3 Hot Bending

If a radius shorter than the minimum specified for cold bending is essential, the plates shall be bent hot at a temperature not greater than 1200F, except for Grades 100 and 100W. If Grades 100 and 100W steel plates to be bent are heated to a temperature greater than 1125F, they must be requenched and tempered in accordance with the producing mill's practice.

11.4.4 Fit of Stiffeners

End bearing stiffeners for girders and stiffeners intended as supports for concentrated loads shall have full bearing (either milled, ground or, on weldable steel in compression areas of flanges, welded as shown on the plans or specified) on the flanges to which they transmit load or from which they receive load. Intermediate stiffeners not intended to support concentrated loads, unless shown or specified otherwise, shall have a tight fit against the compression flange.

11.4.5 Abutting Joints

Abutting joints in compression members of trusses and columns shall be milled or saw-cut to give a square joint and uniform bearing. At other joints, not required to be faced, the opening shall not exceed 3/8 inch.

11.4.6 Facing of Bearing Surfaces

The surface finish of bearing and base plates and other bearing surfaces that are to come in contact with each other or with concrete shall meet the ANSI surface roughness requirements as defined in ANSI B46.1, Surface Roughness, Waviness and Lay, Part I:

Steel slabs	ANSI 2,000
Heavy plates in contact in shoes to be welded	ANSI 1,000
Milled ends of compression members, milled or ground ends of stiffeners and fillers	ANSI 500
Bridge rollers and rockers	ANSI 250
Pins and pin holes	ANSI 125
Sliding bearings	ANSI 125

11.4.7 Straightening Material

The straightening of plates, angles, other shapes, and built-up members, when permitted by the Engineer, shall be done by methods that will not produce fracture or other injury to the metal. Distorted members shall be straightened by mechanical means or, if approved by the Engineer, by carefully planned procedures and supervised application of a limited amount of localized heat, except that heat straightening of Grades 70W, 100 and 100W steel members shall be done only under rigidly controlled procedures, each application subject to the approval of the Engineer. In no case shall the maximum temperature exceed values in the following table:

Grade 70W > 6" from weld	1075°F
Grade 70W < 6" from weld	900°F
Grade 100 or 100W > 6" from weld	1125°F
Grade 100 or 100W < 6" from weld	950°F

In all other steels, the temperature of the heated area shall not exceed 1200° F as controlled by temperature indicating crayons, liquids, or bimetal thermometers.

Parts to be heat straightened shall be substantially free of stress and from external forces, except stresses resulting from mechanical means used in conjunction with the application of heat.

Evidence of fracture following straightening of a bend or buckle will be cause for rejection of the damaged piece.

11.4.8 Bolt Holes

11.4.8.1 Holes for High-Strength Bolts and Unfinished Bolts**

11.4.8.1.1 General

All holes for bolts shall be either punched or drilled. Material forming parts of a member composed of not more than five thicknesses of metal may be punched 1/16 inch larger than the nominal diameter of the bolts whenever the thickness of the material is not greater than 3/4 inch for structural steel, 5/8 inch for high-strength steel or 1/2 inch for quenched and tempered alloy steel, unless subpunching and reaming are required under Article 11.4.8.5.

When there are more than five thicknesses or when any of the main material is thicker than 3/4 inch for structural steel, 5/8 inch for high-strength steel, or 1/2 inch for quenched and tempered alloy steel, all holes shall either be subdrilled and reamed or drilled full size.

When required, all holes shall be either subpunched or subdrilled (subdrilled if thickness limitation governs) 3/16 inch smaller and, after assembling, reamed 1/16 inch larger or drilled full size to 1/16 inch larger than the nominal diameter of the bolts.

When shown on the plans, enlarged or slotted holes are allowed with high-strength bolts.

11.4.8.1.2 Punched Holes

The diameter of the die shall not exceed the diameter of the punch by more than 1/16 inch. If any holes must be enlarged to admit the bolts, such holes shall be reamed. Holes must be clean cut without torn or ragged edges.

** See Article 11.5.5 for bolts included in designation "Unfinished Bolts."

11.4..8.1.3 Reamed or Drilled Holes

Reamed or drilled holes shall be cylindrical, perpendicular to the member, and shall comply with the requirements of Article 11.4.8.1.1 as to size. Where practical, reamers shall be directed by mechanical means. Burrs on the outside surfaces shall be removed. Reaming and drilling shall be done with twist drills, twist reamers or rotobroach cutters. Connecting parts requiring reamed or drilled holes shall be assembled and securely held while being reamed or drilled and shall be match marked before disassembling.

11.4.8.1.4 Accuracy of Holes

Holes not more than 1/32 larger in diameter than the true decimal equivalent of the nominal diameter that may result from a drill or reamer of the nominal diameter are considered acceptable, the slightly conical hole that naturally results from punching operations is considered acceptable. The width of slotted holes which are produced by flame cutting or a combination of drilling or punching and flame cutting shall generally be not more than 1/32 inch greater than the nominal width. The flame cut surface shall be ground smooth.

11.4.8.2 Accuracy of Hole Group

11.4.8.2.1 Accuracy Before Reaming

All holes punched full size, subpunched, or subdrilled shall be so accurately punched that after assembling (before any reaming is done) a cylindrical pin 1/8 inch smaller in diameter than the nominal size of the punched hole may be entered perpendicular to the face of the member, without drifting, in at least 75 percent of the contiguous holes in the same plane. If the requirement is not fulfilled, the badly punched pieces will be rejected. If any hole will not pass a pin 3/16 inch smaller in diameter than the nominal size of the punched hole, this will be cause for rejection.

11.4.8.2.2 Accuracy After Reaming

When holes are reamed or drilled, 85 percent of the holes in any contiguous group shall, after reaming or drilling, show no offset greater than 1/32 inch between adjacent thicknesses of metal.

All steel templates shall have hardened steel bushings in holes accurately dimensioned from the centerlines of the connection as inscribed on the template. The centerlines shall be used in locating accurately the template from the milled or scribed ends of the members.

11.4.8.3 Numerically-Controlled Drilled Field Connections

In lieu of subsized holes and reaming while assembled, or drilling holes full-size while assembled, the Contractor shall have the option to drill or punch bolt holes full-size in unassembled pieces and/or connections including templates for use with matching subsized and reamed holes by means of suitable numerically controlled (N/C) drilling or punching equipment. Full-size punched holes shall meet the requirements of Article 11.4.8.1.

If N/C drilling or punching equipment is used, the Contractor, by means of check assemblies, will be required to demonstrate the accuracy of this drilling or punching procedure in accordance with the provisions of Article 11.5.3.3.

Holes drilled or punched by N/C equipment shall be drilled or punched to appropriate size either through individual pieces, or drilled through any combination of pieces held tightly together.

11.4.8.4 Holes for Ribbed Bolts, Turned Bolts, or Other Approved Bearing Type Bolts

All holes for ribbed bolts, turned bolts, or other approved bearing-type bolts shall be subpunched or subdrilled 3/16 inch smaller than the nominal diameter of the bolt and reamed when assembled, or drilled to a steel template or, after assembling, drilled from the solid at the option of the Fabricator. In any case the finished holes shall provide a driving fit as specified on the plans or in the special provisions.

11.4.8.5 Preparation of Field Connections

Holes in all field connections and field splices of main members of trusses, arches, continuous beam spans, bents, towers (each face), plate girders, and rigid frames shall be subpunched or subdrilled and subsequently reamed while assembled or drilled full size to a steel template. Holes for field splices of rolled beam stringers continuous over floor beams or cross frames may be drilled full size unassembled to a steel template. All holes for floor beams or cross frames may be drilled full size unassembled to a steel template. All holes for floor beam and stringer field end connections shall be subpunched and reamed while assembled or drilled full size to a steel template. Reaming or drilling full size of field connection holes through a steel template shall be done after the template has been located with utmost care as to position and angle and firmly bolted in place. Templates used for reaming matching members, or the opposite faces of a single member, shall be exact duplicates. Templates used for connections on like parts or members shall be so accurately located that the parts or members are duplicates and require no match-marking.

For any connection, in lieu of subpunching and reaming or subdrilling and reaming, the fabricator may, at his option, drill holes full size with all thicknesses or material assembled in proper position.

11.4.9 Pins and Rollers

11.4.9.1 General

Pins and rollers shall be accurately turned to the dimensions shown on the drawings and shall be straight, smooth, and free from flaws. Pins and rollers more than 9 inches in diameter shall be forged rollers and annealed. Pins and rollers 9 inches or less in diameter may be either forged and annealed or cold-finished carbon-steel shafting.

In pins larger than 9 inches in diameter, a hole not less than 2 inches in diameter shall be bored full length along the axis after the forging has been allowed to cool to a temperature below the critical range, under suitable conditions to prevent injury by too rapid cooling, and before being annealed.

11.4.9.2 Boring Pin Holes

Pin holes shall be bored true to the specified diameter, smooth and straight, at right angles with the axis of the member and parallel with each other unless otherwise required. The final surface shall be produced by a finishing cut.

The diameter of the pin hole shall not exceed that of the pin by more than 1/50 inch for pins 5 inches or less in diameter, or by 1/32 inch for larger pins.

The distance outside to outside of end holes in tension members and inside to inside of end holes in compression members shall not vary from that specified more than 1/32 inch. Boring of pin holes in built-up members shall be done after the member has been assembled.

11.4.9.3 Threads for Bolts and Pins

Threads for all bolts and pins for structural steel construction shall conform to the Unified Standard Series UNC ANSI B1.1, Class 2A for external threads and Class 2B for internal threads, except that pin ends having a diameter of 1-3/8 inches or more shall be threaded 6 threads to the inch.

11.4.10 Eyebars

Pin holes may be flame cut at least 2 inches smaller in diameter than the finished pin diameter. All eyebars that are to be placed side by side in the structure shall be securely fastened together in the order that they will be placed on the pin and bored at both ends while so clamped. Eyebars shall be packed and match-marked for shipment and erection. All identifying marks shall be stamped with steel stencils on the edge of one head of each member after fabrication is completed so as to be visible when the bars are nested in place on the structure. Steel die stamps shall be low stress type.

The eyebars shall be straight and free from twists and the pin holes shall be accurately located on the centerline of the bar. The inclination of any bar to the plane of the truss shall not exceed 1/16 inch to a foot.

The edges of eyebars that lie between the transverse centerline of their pin holes shall be cut simultaneously with two mechanically operated torches abreast of each other, guided by a substantial template, in such a manner as to prevent distortion of the plates.

11.4.11 Annealing and Stress Relieving

Structural members which are indicated in the contract to be annealed or normalized shall have finished machining, boring, and straightening done subsequent to heat treatment. Normalizing and annealing (full annealing) shall be as specified in ASTM E44. The temperatures shall be maintained uniformly throughout the furnace during the heating and cooling so that the temperature at no two points on the member will differ by more than 100°F at any one time.

Members of Grades 100/100W or Grade 70W steels shall not be annealed or normalized and shall be stress relieved only with the approval of the Engineer.

A record of each furnace charge shall identify the pieces in the charge and show the temperatures and schedule actually used. Proper instruments, including recording pyrometers, shall be provided for determining at any time the temperatures of members in the furnace. The records of the treatment operation shall be available to and meet the approval of the Engineer. The holding temperature for stress relieving Grades 100/100W and Grade 70W steels shall not exceed 1125°F and 1075°F, respectively.

Members, such as bridge shoes, pedestals, or other parts that are built up by welding sections of plate together shall be stress relieved in accordance with the procedure of Section 4.4 of ANSI/AASHTO/AWS Bridge Welding Code D1.5 when required by the plans, specifications, or special provisions governing the contract.

11.4.12 Curved Girders

11.4.12.1 General

Flanges of curved, welded girders may be cut to the radii shown on the plans or curved by applying heat as specified in the succeeding articles providing the radii is not less than allowed by Article 10.15.2 of Division I.

11.4.12.2 Heat Curving Rolled Beams and Welded Girders

11.4.12.2.1 Materials

Steels that are manufactured to a specified minimum yield point greater than 50,000 psi shall not be heat curved.

11.4.12.2.2 Type of Heating

Beams and girders may be curved by either continuous or V-type heating as approved by the Engineer. For the continuous method, a strip or intermittent strips along the edge of the top and bottom flange shall be heated approximately simultaneously depending on flange widths and thicknesses; the strip shall be of sufficient width and temperature to obtain the required curvature. For the V-type heating, the top and bottom flanges shall be heated in truncated triangular or wedge-shaped areas having their base along the flange edge and spaced at regular intervals along each flange; the spacing and temperature shall be as required to obtain the required curvature, and heating shall progress along the top and bottom flange at approximately the same rate.

For the V-type heating, the apex of the truncated triangular area applied to the inside flange surface shall terminate just before the juncture of the web and the flange is reached. To avoid unnecessary web distortion, special care shall be taken when heating the inside flange surfaces (the surfaces that intersect the web) so that heat is not applied directly to the web. When the radius of curvature is 1,000 feet or more, the apex of the truncated triangular heating pattern applied to the outside flange surface shall extend to the juncture of the flange and web. When the radius of curvature is less than 1,000 feet, the apex of the truncated triangular heating pattern applied to the outside flange surface shall extend past the web for a distance equal to one-eighth of the flange or 3 inches, whichever is less. The truncated triangular pattern shall have an included angle of approximately 15 to 30 degrees, but the base of the triangle shall not exceed 10 inches. Variations in the patterns prescribed above may be made with the approval of the Engineer.

For both types of heating, the flange edges to be heated are those that will be on the inside of the horizontal curve after cooling. Heating both inside and outside flange surfaces is only mandatory when the flange thickness is 1-1/4 inches or greater, in which case, the two surfaces shall be heated concurrently. The maximum temperature shall be prescribed as follows:

11.4.12.2.3 Temperature

The heat-curving operation shall be conducted in such a manner that the temperature of the steel does not exceed 1150°F as measured by temperature indicating crayons or other suitable means. The girder shall not be artificially cooled until after naturally cooling to 600°F. The method of artificial cooling is subject to the approval of the Engineer.

11.4.12.2.4 Position for Heating

The girder may be heat-curved with the web in either a vertical or a horizontal position. When curved in the vertical position, the girder must be braced or supported in such a manner that the tendency of the girder to deflect laterally during the heat-curving process will not cause the girder to overturn.

When curved in the horizontal position, the girder must be supported near its ends and at intermediate points, if required, to obtain a uniform curvature; the bending stress in the flanges due to the dead weight of the girder must not exceed the usual allowable design stress. When the girder is positioned horizontally for heating, intermediate safety catch blocks must be maintained at the mid-length of the girder within 2 inches of the flanges at all times during the heating process to guard against a sudden sag due to plastic flange buckling.

11.4.12.2.5 Sequence of Operations

The girder shall be heat-curved in the fabrication shop before it is painted. The heat curving operation may be conducted either before or after all the required welding of transverse intermediate stiffeners is completed. However, unless provisions are made for girder shrinkage, connection plates and bearing stiffeners shall be located and attached after heat curving. If longitudinal stiffeners are required, they shall be heat-curved or oxygen-cut separately and then welded to the curved girder. When cover plates are to be attached to rolled beams, they may be attached before heat curving if the total thickness of one flange and cover plate is less than 2-1/2 inches and the radius of curvature is greater than 1,000 feet. For other rolled beams with cover plates, the beams must be heat-curved before the cover plates are attached; cover plates must be either heat curved or oxygen-cut separately and then welded to the curved beam.

11.4.12.2.6 Camber

Girders shall be cambered before heat curving. Camber for rolled beams may be obtained by heat-cambering methods approved by the Engineer. For plate girders, the web shall be cut to the prescribed camber with suitable allowance for shrinkage due to cutting, welding, and heat curving. However, subject to the approval of the Engineer, moderate deviations from specified camber may be corrected by a carefully supervised application of heat.

11.4.12.2.7 Measurement of Curvature and Camber

Horizontal curvature and vertical camber shall be measured for final acceptance after all welding and heating operations are completed and the flanges have cooled to a uniform temperature. Horizontal curvature shall be checked with the girder in the vertical position.

11.4.13 Orthotropic-Deck Superstructures

11.4.13.1 General

Dimensional tolerance limits for orthotropic-deck bridge members shall be applied to each completed but unloaded member and shall be as specified in paragraph 3.5 of ANSI/AASHTO/AWS Bridge Welding Code D1.5 except as follows. The deviation from detailed flatness, straightness, or curvature at any point shall be the perpendicular distance from that point to a template edge which has the detailed straightness or curvature and which is in contact with the element at two other points. The term element as used herein refers to individual panels, stiffeners, flanges, or other pieces. The template edge may have any length not exceeding the greatest dimension of the element being examined and, for any panel, not exceeding 1.5 times the least dimension of the panel; it may be placed anywhere within the boundaries of the element. The deviation shall be measured between adjacent points of contact of the template edge with the element; the distance between these adjacent points of contact shall be used in the formulas to establish the tolerance limits for the segment being measured whenever this distance is less than the applicable dimension of the element specified for the formula.

11.4.13.2 Flatness of Panels

(a) The term "panel" as used in this article means a clear area of steel plate surface bounded by stiffeners, webs, flanges, or plate edges and not further subdivided by any such elements. The provisions of this article apply to all panels in the bridge; for plates stiffened on one side only such as orthotropic-deck plates or flanges of box girders, this includes the total clear width on the side without stiffeners as well as the panels between stiffeners on the side with stiffeners.

(b) The maximum deviation from detailed flatness or curvature of a panel shall not exceed the greater of:

$$3/16 \text{ inch or } \frac{D}{144\sqrt{T}} \text{ inch}$$

where

D = the least dimension in inches along the boundary of the panel;
T = the minimum thickness in inches of the plate comprising the panel.

11.4.13.3 Straightness of Longitudinal Stiffeners Subject to Calculated Compressive Stress, Including Orthotropic-Deck Ribs

The maximum deviation from detailed straightness or curvature in any direction perpendicular to its length of a transverse web stiffener or other stiffener not subject to calculated compressive stress shall not exceed:

$$\frac{L}{480}$$

where L = the length of the stiffener or rib between cross members, webs, or flanges, in inches.

11.4.13.4 Straightness of Transverse Web Stiffeners and Other Stiffeners not Subject to Calculated Compressive Stress

The maximum deviation from detailed straightness or curvature in any direction perpendicular to its length of a transverse web stiffener or other stiffener not subject to calculated compressive stress shall not exceed:

$$\frac{L}{240}$$

where L = the length of the stiffener between cross members, webs, or flanges, in inches.

11.4.14 Full Size Tests

When full size tests of fabricated structural members or eyebars are required by the contract, the Contractor shall provide suitable facilities, material, supervision, and labor necessary for making and recording the required tests. The members tested in accordance with the contract shall be paid for in accordance with Article 11.7.2.

11.4.15 Marking and Shipping

Each member shall be painted or marked with an erection mark for identification and an erection diagram showing these marks shall be furnished to the Engineer.

The Contractor shall furnish to the Engineer as many copies of material orders, shipping statements, and erection diagrams as the Engineer may direct. The weights of the individual members shall be shown on the statements. Members weighing more than 3 tons shall have the weights marked thereon. Structural members shall be loaded on trucks or cars in such a manner that they may be transported and unloaded at their destination without being excessively stressed, deformed, or otherwise damaged.

Bolts of one length and diameter and loose nuts or washers of each size shall be packed separately. Pins, small parts and packages of bolts, washers, and nuts shall be shipped in boxes, crates, kegs, or barrels, but the gross weight of any package shall not exceed 300 pounds. A list and description of the contained material shall be plainly marked on the outside of each shipping container.

11.5 ASSEMBLY

11.5.1 Bolting

Surfaces of metal in contact shall be cleaned before assembling. The parts of a member shall be assembled, well pinned, and firmly drawn together before drilling, reaming, or bolting is commenced.

Assembled pieces shall be taken apart, if necessary, for the removal of burrs and shavings produced by the operation. The member shall be free from twists, bends, and other deformation.

The drifting done during assembling shall be only such as to bring the parts into position and not sufficient to enlarge the holes or distort the metal.

11.5.2 Welded Connections

Surfaces and edges to be welded shall be smooth, uniform, clean and free of defects which would adversely affect the quality of the weld. Edge preparation shall be done in accordance with ANSI/AASHTO/AWS Bridge Welding Code D1.5.

11.5.3 Preassembly of Field Connections

11.5.3.1 General

Field connections of main members of trusses, arches, continuous beams, plate girders, bents, towers and rigid frames shall be preassembled prior to erection as necessary to verify the geometry of the completed structure or unit and to verify or prepare field splices. Attaining accurate geometry is the responsibility of the Contractor and he shall propose an appropriate method of preassembly for approval by the Engineer. The method and details of preassembly shall be consistent with the erection procedure shown on the erection plans and camber diagrams prepared by the Contractor and approved by the Engineer. As a minimum, the preassembly procedure shall consist of assembling three contiguous panels accurately adjusted for line and camber. Successive assemblies shall consist of at least one section or panel of the previous assembly (repositioned if necessary and adequately pinned to assure accurate alignment) plus two or more sections or panels added at the advancing end. In the case of structures longer than 150 feet, each assembly shall be not less than 150 feet long regardless of the length of individual continuous panels or sections. At the option of the fabricator, sequence of assembly may start from any location in the structure and proceed in one or both directions so long as the preceding requirements are satisfied.

11.5.3.2 Bolted Connections

For bolted connections holes shall be prepared as outlined in Article 11.4.8. Where applicable, major components shall be assembled with milled ends of compression members in full bearing and then shall have their subsized holes reamed to the specified size while the connections are assembled.

11.5.3.3 Check Assembly—Numerically Controlled Drilling

When the contractor elects to use numerically controlled drilling, a check assembly shall be required for each major structural type of each project, unless otherwise designated on the plans or in the special provisions, and shall consist of at least three contiguous shop sections or, in a truss, all members in at least three contiguous panels but not less than the number of panels associated with three contiguous chord lengths (i.e., length between field splices). Check assemblies should be based on the proposed order of erection, joints in bearings, special complex points, and similar considerations. Special points could be the portals of skewed trusses, for example.

The check assemblies shall preferably be the first sections of each major structural type to be fabricated.

Shop assemblies other than the check assemblies will not be required.

If the check assembly fails in some specific manner to demonstrate that the required accuracy is being obtained, further check assemblies may be required by the Engineer for which there shall be no additional cost to the Department.

Each assembly, including camber, alignment, accuracy of holes, and fit of milled joints, shall be approved by the Engineer before reaming is commenced or before an N/C drilled check assembly is dismantled.

11.5.3.4 Field Welded Connections

For field welded connections the fit of members including the proper space between abutting flanges shall be prepared or verified with the segment preassembled in accordance with Article 11.5.3.1.

11.5.4 Match Marking

Connecting parts preassembled in the shop to assure proper fit in the field shall be match-marked, and a diagram showing such marks shall be furnished to the Engineer.

11.5.5 Connections Using Unfinished, Turned or Ribbed Bolts

11.5.5.1 General

When unfinished bolts are specified, the bolts shall be unfinished, turned, or ribbed bolts conforming to the requirements for Grade A Bolts of Specification for Low-Carbon Steel Externally and Internally Threaded Standard Fasteners, ASTM A 307. Bolts shall have single self-locking nuts or double nuts unless otherwise shown on the plans or in the special provisions. Beveled washers shall be used where bearing faces have a slope of more than 1:20 with respect to a plane normal to the bolt axis. The specifications of this article do not pertain to the use of high-strength bolts. Bolted connections fabricated with high-strength bolts shall conform to Article 11.5.6.

11.5.5.2 Turned Bolts

The surface of the body of turned bolts shall meet the ANSI roughness rating value of 125. Heads and nuts shall be hexagonal with standard dimensions for bolts of the nominal size specified or the next larger nominal size. Diameter of threads shall be equal to the body of the bolt or the nominal diameter of the bolt specified. Holes for turned bolts shall be carefully reamed with bolts furnished to provide for a light driving fit. Threads shall be entirely outside of the holes. A washer shall be provided under the nut.

11.5.5.3 Ribbed Bolts

The body of ribbed bolts shall be of an approved form with continuous longitudinal ribs. The diameter of the body measured on a circle through the points of the ribs shall be 5/64 inch greater than the nominal diameter specified for the bolts.

Ribbed bolts shall be furnished with round heads conforming to ANSI B 18.5 unless otherwise specified. Nuts shall be hexagonal, either recessed or with a washer of suitable thickness. Ribbed bolts shall make a driving fit with the holes. The hardness of the ribs shall be such that the ribs do not mash down enough to permit the bolts to turn in the holes during tightening. If for any reason the bolt twists before drawing tight, the hole shall be carefully reamed and an oversized bolt used as a replacement.

11.5.6 Connections Using High Strength Bolts

11.5.6.1 General

This article covers the assembly of structural joints using AASHTO M164 (ASTM A325) or AASHTO M253 (ASTM A490) high-strength bolts, or equivalent fasteners, tightened to a high tension. The bolts are used in holes conforming to the requirements of Article 11.4.8.

11.5.6.2 Bolted Parts

All material within the grip of the bolt shall be steel, there shall be no compressible material such as gaskets or insulation within the grip. Bolted steel parts shall fit solidly together after the bolts are tightened, and may be coated or uncoated. The slope of the surfaces of parts in contact with the bolt head or nut shall not exceed 1:20 with respect to a plane normal to the bolt axis.

11.5.6.3 Surface Conditions

At the time of assembly, all joint surfaces, including surfaces adjacent to the bolt head and nut, shall be free of scale, except tight mill scale, and shall be free of dirt or other foreign material. Burrs that would prevent solid seating of the connected parts in the snug tight condition shall be removed.

Paint is permitted on the faying surface unconditionally in connections except in slip-critical connections as defined in Article 10.24.1.4, Div. I.

The faying surfaces of slip-critical connections shall meet the requirements of the following paragraphs, as applicable:

(1) In non-coated joints, paint, including any inadvertent overspray, shall be excluded from areas closer than one bolt diameter, but not less than one inch, from the edge of any hole and all areas within the bolt pattern.

(2) Joints specified to have painted faying surfaces shall be blast cleaned and coated with a paint which has been qualified as Class A or B in accordance with the requirements of Art. 10.32.3.2.3, Div. I, except as provided in the following paragraph (3).

(3) Subject to the approval of the Engineer, coating providing a slip coefficient less than 0.33 may be used provided the mean slip coefficient is established by test in accordance with the requirements of Art. 10.32.3.2.3, Div. I, and the allowable slip load per unit area is established.

(4) Coated joints shall not be assembled before the coating has cured for the minimum time used in the qualifying test.

(5) Faying surfaces specified to be galvanized shall be hot-dip galvanized in accordance with AASHTO M111 (ASTM A123), and shall subsequently be roughened by means of hand wire brushing. Power wire brushing is not permitted.

11.5.6.4 Installation

11.5.6.4.1 General

Fasteners of appropriately assigned lot numbers shall be assembled together when installed. Such fasteners shall be protected from dirt and moisture at the job site. Only as many fasteners as are anticipated to be installed and tightened during a work shift shall be taken from protected storage. Fasteners not used shall be returned to protected storage at the end of the shift. Fasteners shall not be cleaned of lubricant that is required to be present in as-delivered condition. Fasteners for slip-critical connections which accumulate rust or dirt resulting from job site conditions shall be cleaned and relubricated prior to installation.

A tension measuring device (a Skidmore-Wilhelm calibrator or other acceptable bolt tension indicating device) shall be at all job sites where high-strength fasteners are being installed and tightened. The tension measuring device shall be used to perform the rotational-capacity test and to confirm (1) the suitability to satisfy the requirements of Table 11.5A of the complete fastener assembly, including lubrication if required to be used in the work, (2) calibration of the wrenches, if applicable, and (3) the understanding and proper use by the bolting crew of the method of tightening to be used. For short grip bolts, direct tension indicators (DTI) with solid plates may be used to perform this test. The DTI shall be first checked with a longer grip bolt in the Skidmore-Wilhelm calibrator. The frequency of confirmation testing, the number of tests to be performed and the test procedure shall be as specified in Arts. 11.5.6.4.4 through 11.5.6.4.7, as applicable. The accuracy of the tension measuring device shall be confirmed by an approved testing agency at least annually.

Fasteners together with washers of size and quality specified, located as required below, shall be installed in properly aligned holes and tightened by any of the methods described in Arts. 11.5.6.4.4 through 11.5.6.4.7 to at least the minimum tension specified in Table 11.5A when all the fasteners are tight. Tightening may be done by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. Impact wrenches, if used, shall be of adequate capacity and sufficiently supplied with air to perform the required tightening of each bolt in approximately 10 seconds.

AASHTO M253 (ASTM A490) fasteners and galvanized AASHTO M164 (ASTM A325) fasteners shall not be reused. Other AASHTO M164 (ASTM A325) bolts may be reused if approved by the Engineer. Touching up or retightening previously tightened bolts which may have been loosened by the tightening of adjacent bolts shall not be considered as reuse provided the snugging up continues from the initial position and does not require greater rotation, including the tolerance, than that required by Table 11.5B.

11.5.6.4.2 Rotational-Capacity Tests

High-strength fasteners, black and galvanized, shall be subjected to job-site rotational-capacity tests performed in accordance with AASHTO M164, Section 8.5, and shall meet the following requirements:

a. After tightening to a snug tight condition, as defined in 11.5.6.4.4, the fastener shall be tightened two times the required number of turns indicated in Table 11.5B, in a Skidmore-Wilhelm Calibrator, or equivalent tension measuring device, without stripping or failure.

b. During this test, the maximum recorded tension shall be equal to or greater than the turn test tension which is 1.15 times the required fastener tension indicated in Table 11.5A.

c. The measured torque at a tension "P," after exceeding the turn test tension required above in b., shall not exceed the value obtained by the following equation:

$$\text{Torque} = 0.25\, PD$$

where

Torque	= Measured torque (ft-lbs)
P	= Measured bolt tension (lbs)
D	= Nominal diameter (ft)

For rotational-capacity tests, the use of washers is required even though their use may not be required in the actual installation.

11.5.6.4.3 Requirement for Washers

Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, a hardened bevelled washer shall be used to compensate for the lack of parallelism.

Hardened beveled washers for American Standard Beams and Channels shall be required and shall be square or rectangular, shall conform to the requirements of AASHTO M293 (ASTM F436), and shall taper in thickness.

Where necessary, washers may be clipped on one side to a point not closer than 7/8 of the bolt diameter from the center of the washer.

Hardened washers are not required for connections using AASHTO M164 (ASTM A325) and AASHTO M253 (ASTM A490) bolts except as follows:

Hardened washers shall be used under the element turned in tightening when the tightening is to be performed by calibrated wrench method.

Irrespective of the tightening method, hardened washers shall be used under both the head and the nut when AASHTO M253 (ASTM A490) bolts are to be installed in material having a specified yield point less than 40 ksi.

Where AASHTO M164 (ASTM A325) bolts of any diameter or AASHTO M253 (ASTM A490) bolts equal to or less than 1 inch in diameter are to be installed in oversize or short-slotted holes in an outer ply, a hardened washer conforming to ASTM F436 shall be used.

When AASHTO M253 (ASTM A490) bolts over 1 inch in diameter are to be installed in an oversize or short-slotted hole in an outer ply, hardened washers conforming to ASTM F436 except with 5/16-inch minimum thickness shall be used under both the head and the nut in lieu of standard thickness hardened washers. Multiple hardened washers with combined thickness equal to or greater than 5/16-inch do not satisfy this requirement.

Where AASHTO M164 (ASTM A325) bolts of any diameter or AASHTO M253 (ASTM A490) bolts equal to or less than 1 inch in diameter are to be installed in a long slotted hole in an outer ply, a plate washer or continuous bar of at least 5/16-inch thickness with standard holes shall be provided. These washers or bars shall have a size sufficient to completely cover the slot after installation and shall be of structural grade material, but need not be hardened except as follows. When AASHTO M253 (ASTM A490) bolts over 1 inch in diameter are to be used in long slotted holes in external plies, a single hardened washer conforming to ASTM F436 but with 5/16-inch minimum thickness shall be used in lieu of washers or bars of structural grade material. Multiple hardened washers with combined thickness equal to or greater than 5/16-inch do not satisfy this requirement.

Alternate design fasteners meeting the requirements of Article 11.3.2.6 with a geometry which provides a bearing circle on the head or nut with a diameter equal to or greater then the diameter of hardened washers meeting the requirements of ASTM F436 satisfy the requirements for washers specified herein and may be used without washers.

11.5.6.4.4 Turn-of-Nut Tightening

When turn-of-nut tightening is used, hardened washers are not required except as may be specified in Article 11.5.6.4.3.

A representative sample of not less than three bolt and nut assemblies of each diameter, length and grade to be used in the work shall be checked at the start of work in a device capable of indicating bolt tension. The test shall demonstrate that the method for estimating the snug tight condition and controlling the turns from snug tight to be used by the bolting crew develops a tension not less than five percent greater than the tension required by Table 11.5A. Periodic retesting shall be performed when ordered by the Engineer.

Bolts shall be installed in all holes of the connection and brought to a snug tight condition. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. This may be attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench.

Snug tightening shall progress systematically from the most rigid part of the connection to the free edges, and then the bolts of the connection shall be retightened in a similar systematic manner as necessary until all bolts are simultaneously snug tight and the connection is fully compacted. Following this initial operation all bolts in the connection shall be tightened further by the applicable amount of rotation specified in Table 11.5B. During the tightening operation there shall be no rotation of the part not turned by the wrench. Tightening shall progress systematically from the most rigid part of the joint to its free edges.

11.5.6.4.5 Calibrated Wrench Tightening

Calibrated wrench tightening may be used only when installation procedures are calibrated on a daily basis and when a hardened washer is used under the element turned in tightening. Standard torques determined from tables or from formulas which are assumed to relate torque to tension are not acceptable.

When calibrated wrenches are used for installation, they shall be set to provide a tension not less than 5 percent in excess of the minimum tension specified in Table 11.5A. The installation procedures shall be calibrated at least once each working day for each bolt diameter, length and grade using fastener assemblies that are being installed in the work. Calibration shall be accomplished in a device capable of indicating actual bolt tension by tightening three typical bolts of each diameter, length and grade from the bolts being installed and with a hardened washer from the washers being used in the work under the element turned in tightening. Wrenches shall be recalibrated when significant difference is noted in the surface condition of the bolts, threads, nuts or washers. It shall be verified during actual installation in the assembled steel work that the wrench adjustment selected by the calibration does not produce a nut or bolt head rotation from snug tight greater than that permitted in Table 11.5B. If manual torque wrenches are used, nuts shall be turned in the tightening direction when torque is measured.

When calibrated wrenches are used to install and tension bolts in a connection, bolts shall be installed with hardened washers under the element turned in tightening bolts in all holes of the connection and brought to a snug tight condition. Following this initial tightening operation, the connection shall be tightened using the calibrated wrench. Tightening shall progress systematically from the most rigid part of the joint to its free edges. The wrench shall be returned to "touch up" previously tightened bolts which may have been relaxed as a result of the subsequent tightening of adjacent bolts until all bolts are tightened to the prescribed amount.

11.5.6.4.6 Installation of Alternate Design Bolts

When fasteners which incorporate a design feature intended to indirectly indicate the bolt tension or to automatically provide the tension required by Table 11.5A and which have been qualified under Art. 11.3.2.6 are to be installed, a representative sample of not less than three bolts of each diameter, length and grade shall be checked at the job site in a device capable of indicating bolt tension. The test assembly shall include flat-hardened washers, if required in the actual connection, arranged as in the actual connections to be tensioned. The calibration test shall demonstrate that each bolt develops a tension not less than five percent greater than the tension required by Table 11.5A. Manufacturer's installation procedure shall be followed for installation of bolts in the calibration device and in all connections. Periodic retesting shall be performed when ordered by the Engineer.

When alternate design fasteners which are intended to control or indicate bolt tension of the fasteners are used, bolts shall be installed in all holes of the connection and initially tightened sufficiently to bring all plies of the joint into firm contact but without yielding or fracturing the control or indicator element of the fasteners. All fasteners shall then be further tightened, progressing systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final twist-off of the control or indicator element of individual fasteners.

11.5.6.4.7 Direct Tension Indicator Tightening

When tightening of bolts using direct tension indicator devices is used, a representative sample of not less than three devices for each diameter and grade of fastener to be used in the work shall be assembled in a calibration device capable of indicating bolt tension. The test assembly shall include flat-hardened washers, if required in the actual connection, arranged as those in the actual connections to be tensioned. The calibration test shall demonstrate that the device indicates a tension not less than five percent greater than that required by Table 11.5A.

Manufacturer's installation procedure shall be followed for installation of bolts in the calibration device and in all connections. Special attention shall be given to proper installation of flat-hardened washers when direct tension indicator devices are used with bolts installed in oversize or slotted holes and when the load indicating devices are used under the turned element.

When bolts are installed using direct tension indicators meeting the requirements of ASTM F959, bolts shall be installed in all holes of the connection and brought to snug tight conditions. Snug tight is indicated by partial compression of the direct tension indicator protrusions. All fasteners shall then be tightened, progressing systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners.

In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final tightening to deform the protrusion to the specified gap.

11.5.6.4.8 Lock-Pin and Collar Fasteners

The installation of lock-pin and collar fasteners shall be by methods and procedures approved by the Engineer.

TABLE 11.5A: Required Fastener Tension
Minimum Bolt Tension in Pounds*

Bolt Size inches	AASHTO M164 ASTM A325	AASHTO M253 ASTM A490
1/2	12000	15000
5/8	19000	24000
3/4	28000	35000
7/8	39000	49000
1	51000	64000
1-1/8	56000	80000
1-1/4	71000	102000
1-3/8	85000	121000
1-1/2	103000	148000

* Equal to 70% of specified minimum tensile strength of bolts (as specified in ASTM Specifications for tests of full-size A325 and A490 bolts with UNC threads loaded in axial tension) rounded to the nearest kip.

TABLE 11.5B: Nut Rotation from the Snug-Tight Condition[a,b]
Geometry of Outer Faces of Bolted Parts

Bolt length measured from underside of head to end of bolt.	Both faces normal to bolt axis.	One face normal to bolt axis and other face sloped not more than 1:20. Bevel washer not used.	Both faces sloped not more than 1:20 from normal to bolt axis. Bevel washers not used.
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 diameters	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 diameters[c]	2/3 turn	5/6 turn	1 turn

[a] Nut rotation is relative to bolt, regardless of the element (nut or bolt) being turned. For bolts installed by 1/2 turn and less, the tolerance should be plus or minus 30 degrees; for bolts installed by 2/3 turn and more, the tolerance should be plus or minus 45 degrees.

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

[c] No research work has been performed by the Research Council Riveted and Bolted Structural Joints to establish the turn-of-nut procedure when bolt lengths exceed 12 diameters. Therefore, the required rotation must be determined by actual tests in a suitable tension device simulating the actual conditions.

11.5.6.4.9 Inspection

Either the Engineer or the Contractor in the presence of the Engineer, at the Engineer's option, shall inspect the tightened bolts using an inspection torque wrench.

Three bolts of the same grade, size, and condition as those under inspection shall be placed individually in a device calibrated to measure bolt tension. This calibration operation shall be done at least once each inspection day. There shall be a washer under the part turned in tightening each bolt if washers are used on the structure. If washers are not used on the structure, the material used in the tension measuring device which abuts the part turned shall be of the same specification as that used on the structure. In the calibrated device, each bolt shall be tightened by any convenient means to the specified tension. The inspecting wrench shall then be applied to the tightened bolt to determine the torque required to turn the nut or head 5 degrees (approximately 1 inch at a 12-inch radius) in the tightening direction. The average of the torque required for all three bolts shall be taken as the job-inspection torque.

Ten percent (at least two) of the tightened bolts on the structure represented by the test bolts shall be selected at random in each connection. The job-inspection torque shall then be applied to each with the inspecting wrench turned in the tightening direction. If this torque turns no bolt head or nut, the bolts in the connection will be considered to be properly tightened. But if the torque turns one or more bolt heads or nuts, the job-inspection torque shall then be applied to all bolts in the connection. Any bolt whose head or nut turns at this stage shall be tightened and reinspected. The Contractor may, however, retighten all the bolts in the connection and resubmit it for inspection.

11.5.7 Welding

Welding, welder qualifications, prequalification of weld details and inspection of welds shall conform to the requirements of the ANSI/AASHTO/AWS Bridge Welding Code D1.5.

Brackets, clips, shipping devices or other material not required by the plans or special provisions shall not be welded or tacked to any member unless shown on the shop drawings and approved by the Engineer.

11.6 ERECTION

11.6.1 General

The Contractor shall provide all tools, machinery and equipment necessary to erect the structure.

Falsework and forms shall be in accordance with the requirements of Section 3, "Temporary Works."

11.6.2 Handling and Storing Materials

Material to be stored at the job site shall be placed on skids above the ground. It shall be kept clean and properly drained. Girders and beams shall be placed upright and shored. Long members, such as columns and chords, shall be supported on skids placed near enough together to prevent injury from deflection. If the contract is for erection only, the Contractor shall check the material turned over to him against the shipping lists and report promptly in writing any shortage or injury discovered. He shall be responsible for the loss of any material while in his care, or for any damage caused to it after being received by him.

11.6.3 Bearings and Anchorages

Bridge bearings shall be furnished and installed in conformance with Section 18 of these Specifications.

If the steel superstructure is to be placed on a substructure that was built under a separate contract, the Contractor shall verify that the masonry has been constructed in the right location and to the correct lines and elevations before ordering materials.

11.6.4 Erection Procedure

11.6.4.1 Conformance to Drawings

The erection procedure shall conform to the erection drawings submitted in accordance with Article 11.2.2. Any modifications to or deviations from this erection procedure will require revised drawings and verification of stresses and geometry.

11.6.4.2 Erection Stresses

Any erection stresses that are induced in the structure as a result of the use of a method of erection or equipment which differs from that shown on the plans or specified, and which will remain in the finished structure as locked-in stresses shall be accounted for by the Contractor. He may provide additional material at his expense to keep both temporary and final stresses within the allowable limits used in design.

The Contractor will be responsible for providing temporary bracing or stiffening devices to accommodate handling stresses in individual members or segments of the structure during erection.

11.6.4.3 Maintaining Alignment and Camber

During erection the Contractor will be responsible for supporting segments of the structure in a manner that will produce the proper alignment and camber in the completed structure. Cross frames and diagonal bracing shall be installed as necessary during the erection process to provide stability and assure correct geometry. Temporary bracing, if necessary at any stage of erection, shall be provided by the Contractor.

11.6.5 Field Assembly

The parts shall be accurately assembled as shown on the plans or erection drawings, and any match-marks shall be followed. The material shall be carefully handled so that no parts will be bent, broken, or otherwise damaged. Hammering which will injure or distort the members shall not be done. Bearing surfaces and surfaces to be in permanent contact shall be cleaned before the members are assembled. Splices and field connections shall have one-half of the holes filled with bolts and cylindrical erection pins (half bolts and half pins) before installing and tightening the balance of high-strength bolts. Splices and connections carrying traffic during erection shall have three-fourths of the holes so filled.

Fitting-up bolts may be the same high-strength bolts used in the installation. If other fitting-up bolts are used they shall be of the same nominal diameter as the high-strength bolts, and cylindrical erection pins shall be 1/32 inch larger.

11.6.6 Pin Connections

Pilot and driving nuts shall be used in driving pins. They shall be furnished by the Contractor without charge. Pins shall be so driven that the members will take full bearing on them. Pin nuts shall be screwed up tight and the threads burred at the face of the nut with a pointed tool.

11.6.7 Misfits

The correction of minor misfits involving minor amounts of reaming, cutting, and chipping will be considered a legitimate part of the erection. However, any error in the shop fabrication or deformation resulting from handling and transporting will be cause for rejection.

The Contractor shall be responsible for all misfits, errors, and damage and shall make the necessary corrections and replacements.

11.7 MEASUREMENT AND PAYMENT

11.7.1 Method of Measurement

Pay quantities for each type of steel and iron will be measured by the pound computed from dimensions shown on the plans using the following rules and assumptions:

Unit Weights, Pound per Cubic Foot

Cast Iron	445.0
Malleable Iron	470.0
Wrought Iron	487.0
Steel-rolled or cast	490.0

The weights of rolled shapes will be computed on the basis of their nominal weights per foot as shown on the drawings, or listed in the handbooks.

The weights of plates will be computed on the basis of the nominal weight for their width and thickness as shown on the drawings, plus an estimated overrun computed as one-half the "Permissible Variation in Thickness and Weight" as tabulated in Specification, "General Requirements for Delivery of Rolled Steel Plates, Shapes, Steel Piling, and Bars for Structural Use," AASHTO M160 (ASTM A6).

The weight of castings will be computed from the dimensions shown on the approved shop drawings, deducting for open holes. To this weight will be added 5 percent allowance for fillets and overrun. Scale weights may be substituted for computed weights in the case of castings or of small complex parts for which accurate computations of weight would be difficult.

The weight of temporary erection bolts, shop and field paint, boxes, crates, and other containers used for shipping, and materials used for supporting members during transportation and erection, will not be included.

The weight of any additional material required by Article 11.6.4.2 to accommodate erection stresses resulting from the Contractor's choice of erection methods will not be included.

In computing pay weight on the basis of computed net weight the following stipulations in addition to those in the foregoing paragraphs will apply.

(a) The weight will be computed on the basis of the net finished dimensions of the parts as shown on the approved shop drawings, deducting for copes, cuts, clips, and all open holes, except bolt holes.

(b) The weight of heads, nuts, single washers, and threaded stick-through of all high tensile strength bolts, both shop and field, will be included on the basis of the following weights:

Diameter of Bolt (in.)	Weight per 100 bolts (lbs.)
1/2	19.7
5/8	31.7
3/4	52.4
7/8	80.4
1	116.7
1-1/8	165.1
1-1/4	212.0
1-3/8	280.0
1-1/2	340.0

(c) The weight of fillet welds will be as follows:

Size of Fillet Weld Inches	Weight—Pounds per Linear Foot
3/16	0.08
1/4	0.14
5/16	0.22
3/8	0.30
1/2	0.55
5/8	0.80
3/4	1.10
7/8	1.50
1	2.00

(d) To determine the pay quantities of galvanized metal, the weight to be added to the calculated weight of base metal for the galvanizing will be determined from the weights of zinc coatings specified by AASHTO M111 (ASTM A123).

(e) No allowance will be made for the weight of paint.

11.7.2 Basis of Payment

The contract price for fabrication and erection of structural steel shall be considered to be full compensation for the cost of all labor, equipment, materials, transportation, and shop and field painting, if not otherwise provided for, necessary for the proper completion of the work in accordance with the contract. The contract price for fabrication without erection shall be considered to be full compensation for the cost of all labor, equipment and materials necessary for the proper completion of the work, other than erection and field assembly, in accordance with the contract.

Under contracts containing an item for structural steel, all metal parts other than metal reinforcement for concrete, such as anchor bolts and nuts, shoes, rockers, rollers, bearing and slab plates, pins and nuts, expansion dams, roadway drains and scuppers, weld metal, bolts embedded in concrete, cradles and brackets, railing, and railing pots shall be paid for as structural steel unless otherwise stipulated.

Payment will be made on a pound-price or a lump sum basis as required by the terms of the contract, but unless stipulated otherwise, it shall be on a pound-price basis.

For members comprising both carbon steel and other special steel or material, when separate unit prices are provided for same, the weight of each class of steel in each such member shall be separately computed, and paid for at the contract unit price therefor.

Full-size members which are tested in accordance with the specifications, when such tests are required by the contract, shall be paid for at the same rate as for comparable members for the structure. The cost of testing including equipment, labor and incidentals shall be included in the contract price for structural steel. Members which fail to meet the contract requirements, and members rejected as a result of tests, will not be paid for by the Department.

APPENDIX F

LOAD AND RESISTANCE FACTOR DESIGN

Specification for Structural Joints Using ASTM A325 or A490 Bolts

Approved by Research Council on Structural Connections
of the Engineering Foundation, **June 8, 1988.**
Endorsed by American Institute of Steel Construction
Endorsed by Industrial Fasteners Institute

AMERICAN INSTITUTE OF STEEL CONSTRUCTION, INC.
One East Wacker Drive, Suite 3100, Chicago, IL 60601-2001

PREFACE

The purpose of the Research Council on Structural Connections is to stimulate and support such investigation as may be deemed necessary and valuable to determine the suitability and capacity of various types of structural connections, to promote the knowledge of economical and efficient practices relating to such structural connections, and to prepare and publish related standards and such other documents as necessary to achieving its purpose.

The Council membership consists of qualified structural engineers from the academic and research institutions, practicing design engineers, suppliers, and manufacturers of threaded fasteners, fabricators and erectors and code writing authorities. Each version of the Specification is based upon deliberations and letter ballot of the full Council membership.

The first *Specification for Assembly of Structural Joints Using High Tensile Steel Bolts* approved by the Council was published in January 1951. Since that time the Council has published 12 succeeding editions each based upon past successful usage, advances in the state of knowledge and changes in engineering design practice. This version of the Council's *Load and Resistance Factor Design Specification* is significantly reorganized and revised from earlier versions.

The intention of the Specifications is to cover the design criteria and normal usage and practices involved in the everyday use of high-strength bolts in steel-to-steel structural connections. It is not intended to cover the full range of structural connections using threaded fasteners nor the use of high-strength bolts other than those included in ASTM A325 or ASTM A490 Specifications nor the use of ASTM A325 or A490 bolts in connections with material other than steel within the grip.

A Commentary has been prepared to accompany these Specifications to provide background and aid the user to better understand and apply the provisions.

The user is cautioned that independent professional judgment must be exercised when data or recommendations set forth in these Specifications are applied. The design and the proper installation and inspection of bolts in structural connections is within the scope of expertise of a competent licensed architect, structural engineer or other licensed professional for the application of the principles to a particular case.

LOAD AND RESISTANCE FACTOR DESIGN

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1. Scope

This Specification relates to the load and resistance factor design of structural joints using ASTM A325 high-strength bolts, ASTM A490 high-strength bolts or equivalent fasteners, and for the installation of such bolts in connections of structural steel members. The Specification relates only to those aspects of the connected materials that bear upon the performance of the fasteners.

Design and construction shall conform to an applicable load and resistance factor design code or specification for structures of carbon, high-strength low alloy steel or quenched and tempered structural steel. Load and resistance factor design is 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 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 capacity, and thus generally are related to safety. Serviceability limit states are usually related to performance under normal service conditions, and thus usually are not related to strength or safety. (See Commentary.) The term "resistance" includes both strength limit states and serviceability limit states.

The design strength, ϕR_n (nominal strength multiplied by a resistance factor), of each structural component or assemblage must equal or exceed the effect of the factored loads (nominal loads multiplied by load factors, with due recognition for load combinations). Thus, both the load factor and the resistance factor must be known to determine the reliability of the design, identified in load and resistance factor design as the "safety index." Although the load factors are not stated in this Specification, load criteria contained in American National Standard "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures," ANSI A58.1-1982, were used as the basis for determining the resistance factors. For construction governed by other design load criteria, appropriate adjustment of resistance factors may be required.

The attached Commentary provides background information in order that the user may better understand the provisions of the Specification.

2. Bolts, Nuts, Washers and Paint

(a) Bolt Specifications. Bolts shall conform to the requirements of the current edition of the American Society for Testing and Materials' "Specification for High-Strength Bolts for Structural Steel Joints," ASTM A325, or "Specification for Heat Treated, Steel Structural Bolts, 150 ksi Tensile Strength," ASTM A490, except as provided in paragraph (d) of this section. The Engineer of Record shall specify the type of bolts to be used.

(b) Bolt Geometry. Bolt dimensions shall conform to the current American National Standards Institute's standard, "Heavy Hex Structural Bolts," ANSI Standard B18.2.1, except as provided in paragraph (d) of this section. The length of bolts shall be such that the end of the bolt will be flush with or project beyond the face of the nut when properly installed.

(c) Nut Specifications. Nuts shall conform to the current chemical and mechanical requirements of the American Society for Testing and Materials' "Specification for Carbon and Alloy Steel Nuts," ASTM A563, or "Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service," ASTM A194. The grade and surface finish of nuts for each type shall be as follows:

A325 Bolt Type	Nut Specification, Grade and Finish
1 and 2, plain (uncoated)	A563 C, C3, D, D3 and DH3 or A194 2 and 2H; plain
1 and 2, galvanized	A563 DH or A194 2H; galvanized and lubricated
3, plain	A563 C3 and DH3; plain

A490 Bolt Type	Nut Specification, Grade and Finish
1 and 2, plain	A563 DH and DH3 or A194 2H; plain
3, plain	A563 DH3; plain

Nut dimensions shall conform to the current American National Standards Institute's standard, "Heavy Hex Nuts," ANSI Standard B18.2.2., except as provided in paragraph (d) of this section.

(d) Alternative Fastener Designs. Other fasteners or fastener assemblies which meet the materials, manufacturing and chemical composition requirements of ASTM A325 or ASTM A490, as applicable, and which meet the mechanical property requirements of the same specifications in full-size tests, and which have a body diameter and bearing areas under the head and nut not less than those provided by a bolt and nut of the same nominal dimensions prescribed by paragraphs 2(b) and 2(c), may be used subject to the approval of the Engineer of Record. Such alternative fasteners may differ in other dimensions from those of the specified bolts and nuts. Their installation procedure and inspection may differ from procedures specified for regular high-strength bolts in Sections 8 and 9. When a different installation procedure or inspection is used, it shall be detailed in a supplemental specification applying to the alternative fastener, and that specification must be approved by the Engineer of Record.

(e) Washers. Flat circular washers and square or rectangular beveled washers shall conform to the current requirements of the American Society for Testing and Materials' "Specification for Hardened Steel Washers," ASTM F436.

(f) Load Indicating Devices. Load indicating devices may be used in conjunction with bolts, nuts and washers specified in 2(a) through 2(e). Load indicating devices shall conform to the requirements of American Society for Testing and Materials' "Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners," ASTM F959. Subject to the approval of the Engineer of Record, direct tension indicating devices different from those meeting the requirements of ASTM F959 may be used provided they satisfy the requirements of 8(d)(4). If their installation procedure and inspection are not identical to that specified in 8(d)(4), they shall be detailed in supplemental specifications provided by the manufacturer and subject to the approval of the Engineer of Record.

(g) Faying Surface Coatings. Paint, if used on faying surfaces of connections which are not specified to be slip critical, may be of any formulation. Paint, used on the faying surfaces of connections specified to be slip critical, shall be qualified by test in accordance with "Test Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints" as published by the Research Council on Structural Connections. (See Appendix A.) Manufacturer's certification shall include a certified copy of the test report.

3. Bolted Parts

(a) Connected Material. All material within the grip of the bolt shall be steel. There shall be no compressible material such as gaskets or insulation within the grip. Bolted steel parts shall fit solidly together after the bolts are tightened, and may be coated or noncoated. The slope of the surfaces of parts in contact with the bolt head or nut shall not exceed 1:20 with respect to a plane normal to the bolt axis.

(b) Surface Conditions. When assembled, all joint surfaces, including surfaces adjacent to the bolt head and nut, shall be free of scale, except tight mill scale, and shall be free of dirt or other foreign material. Burrs that would prevent solid seating of the connected parts in the snug tight condition shall be removed.

Paint is permitted unconditionally on the faying surfaces in connections except in slip-critical connections as defined in Section 5(a).

The faying surfaces of slip-critical connections shall meet the requirements of the following paragraphs, as applicable.

(1) In noncoated joints, paint, including any inadvertent overspray, shall be excluded from areas closer than one bolt diameter but not less

than one inch from the edge of any hole and all areas within the bolt pattern.

(2) Joints specified to have painted faying surfaces shall be blast cleaned and coated with a paint which has been qualified as Class A or B in accordance with the requirements of paragraph 2(g), except as provided in 3(b)3.

(3) Subject to the approval of the Engineer of Record, coatings providing a slip coefficient less than 0.33 may be used provided the mean slip coefficient is established by test in accordance with the requirements of paragraph 2(g), and the design slip resistance, ϕR_s, calculated in accordance with the formula in Section 5(b) or 5(c).

(4) Coated joints shall not be assembled before the coatings have cured for the minimum time used in the qualifying test.

(5) Faying surfaces specified to be galvanized shall be hot-dip galvanized in accordance with American Society for Testing and Materials' "Specification for Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars, and Strip," ASTM A123 and shall subsequently be roughened by means of hand wire brushing. Power wire brushing is not permitted.

(c) Hole Types. Hole types recognized under this specification are standard holes, oversize holes, short slotted holes and long slotted holes. The nominal dimensions for each type hole shall be not greater than those shown in Table 1. Holes not more than $\frac{1}{32}$ inch larger in diameter than the true decimal equivalent of the nominal diameter that may result from a drill or reamer of the nominal diameter are considered acceptable. The slightly conical hole that naturally results from punching operations is considered acceptable. The width of slotted holes which are produced by flame cutting or a combination of drilling or punching and flame cutting shall generally be not more than $\frac{1}{32}$ inch greater than the nominal width except that gouges not more than $\frac{1}{16}$ inch deep shall be permitted. For statically loaded connections, the flame cut surface need not be ground. For dynamically loaded connections, the flame cut surface shall be ground smooth.

4. Design of Bolted Connections

Expressions for design strengths, ϕR_n, of bolts subject to axial tension, shear and combined shear and tension are given in 4(a) and 4(b). They are to be compared to the effect of the factored loads. The design resistances of bolts subject to cyclic application of axial tension are given in 4(e). They are to be compared to effect of cyclically applied nominal (service) loads.

(a) Tension and Shear Strength Limit States. The design strength in axial tension for A325 and A490 bolts which are tightened to the minimum fastener tension specified in Table 4 is ϕR_n. The design strength in shear for A325 and A490 bolts, independent of the installed bolt pretension, is ϕR_n where:

$$R_n = F_n A_b \qquad \text{(LRFD 4.1)}$$

Table 1. Nominal Hole Dimensions

Bolt Dia.	Hole Dimensions			
	Standard (Dia.)	Oversize (Dia.)	Short Slot (Width × Length)	Long Slot (Width × Length)
1/2	9/16	5/8	9/16 × 11/16	9/16 × 1 1/4
5/8	11/16	13/16	11/16 × 7/8	11/16 × 1 9/16
3/4	13/16	15/16	13/16 × 1	13/16 × 1 7/8
7/8	15/16	1 1/16	15/16 × 1 1/8	15/16 × 2 3/16
1	1 1/16	1 1/4	1 1/16 × 1 5/16	1 1/16 × 2 1/2
≥1 1/8	d + 1/16	d + 5/16	(d + 1/16) × (d + 3/8)	(d + 1/16) × (2.5 × d)

In this expression:
R_n = nominal strength of a bolt subject to axial tension or shear, kips
F_n = nominal strength from Table 2 for appropriate kind of load, ksi
A_b = area of bolt corresponding to nominal diameter, in.^{2}
ϕ = resistance factor from Table 2.

(b) **Combined Tension and Shear Strength Limit State.** In bearing connections in which the applied shear force is greater than ⅓ the design shear strength according to 4(a), the design strength in axial tension for A325 and A490 bolts is ϕR_n where:

$$R_n = F_{nt} A_b \qquad \text{(LRFD 4.2)}$$

Where
R_n = nominal tension strength of a bolt subject to concurrent shear, kips
F_{nt} = nominal tension strength of a bolt as calculated by formulas in Table 3, ksi
A_b = area of bolt corresponding to nominal diameter, in.^{2}
ϕ = resistance factor equal to 0.75

In Table 3, f_v equals the shear force on the bolt in ksi.

(c) **Bearing Strength Limit State.** The design bearing strength on the connected material for all bolts in a connection with two or more bolts in the line of force in standard, oversize, or short slotted holes when the edge distance in direction of force is not less than $1\frac{1}{2}d$ and the distance center to center of bolts is not less than $3d$ is ϕR_n where:

$$R_n = 2.4dtF_u \qquad \text{(LRFD 4.3)}$$

The design bearing strength on the connected material for all bolts in a connection with two or more bolts in the line of force in long slotted holes perpendicular to the direction of force when the edge distance, L, is not less than $1\frac{1}{2}d$ and the distance center to center of bolts is not less than 3d is ϕR_n where:

$$R_n = 2.0dtF_u \qquad \text{(LRFD 4.4)}$$

The design bearing strength on the connected material for the bolt nearest to the free edge in the direction of force when two or more bolts are in the line of force in standard, oversize, or short slotted holes but with the

Table 2. Nominal Strength of Fasteners

Load Condition	Nominal Strength (ksi)		Resistance Factor, ϕ
	A325	A490	
Applied Static Tension.[a,b,c]	90	113	0.75
Shear on bolt with threads in shear plane.	48[d]	60[d]	0.75
Shear on bolt without threads in shear plane.	60[d]	75[d]	0.75

a. Bolts must be tensioned to requirements of Table 4.
b. See 4(e) for bolts subject to tensile fatigue.
c. Except as required by 4(b).
d. In shear connections transmitting axial force whose length between extreme fasteners measured parallel to the line of force exceeds 50 inches, tabulated values shall be reduced 20 percent.

Table 3. Nominal Tension Strength for Bolts in Bearing Connections (Nominal Tensile Strength, F_{nt}, ksi.)

Fastener Grade	Threads Not Excluded from Shear Plane	Threads Excluded from Shear Plane
ASTM A325	$(90^2\text{-}3.52f_v^2)^{0.5}$	$(90^2\text{-}2.25f_v^2)^{0.5}$
ASTM A490	$(113^2\text{-}3.54f_v^2)^{0.5}$	$(113^2\text{-}2.27f_v^2)^{0.5}$

edge distance less than 1½d and for a single bolt in the line of force is ϕR_n where:

$$R_n = LtF_u \leq 3.0dtF_u \qquad \text{(LRFD 4.5)}$$

When two or more bolts are in the line of force in standard, oversize, or short slotted holes and if deformation around the bolt holes is not a design consideration, the design strength in bearing for the individual bolts of a connection may be taken as ϕR_n where:

$$R_n = LtF_u \leq 3.0dtF_u \qquad \text{(LRFD 4.6)}$$

In the foregoing:
R_n = nominal bearing strength of connected material, kips
F_u = specified minimum tensile strength of the connected part, ksi
L = distance in the direction of the force from the center of a standard hole or transverse slotted hole to the edge of the connected part or the distance center to center of standard holes or transverse slots, as applicable, in.
d = nominal diameter of bolt, in.
t = thickness of connected material, in.
ϕ = resistance factor = 0.75

(d) Prying Action. The force in bolts required to support loads by means of direct tension shall be calculated considering the effects of the external load and any tension resulting from prying action produced by deformation of the connected parts.

(e) Tensile Fatigue. When subject to tensile fatigue loading, the tensile stress in the bolt due to the nominal (service) load plus the prying force resulting from cyclic application of nominal load shall not exceed the following design resistances in kips per square inch. The nominal diameter of the bolt shall be used in calculating the bolt stress. In no case shall the calculated prying force exceed 60 percent of the externally applied load.

Number of Cycles	A325	A490
Not more than 20,000	44	54
From 20,000 to 500,000	40	49
More than 500,000	31	38

Bolts subject to tensile fatigue loading must be tensioned to requirements of Table 4.

5. Design Check for Slip Resistance

(a) Slip-Critical Joints. Joints in which, in the judgment of the Engineer of Record, slip would be detrimental to the behavior of the joint, are defined as slip-critical. As discussed in the Commentary, these include but are not necessarily limited to joints subject to fatigue or significant load reversal, joints with bolts in oversize holes or slotted holes with the applied force approximately in the direction of the long dimension of the slots and joints in which welds and bolts share in transmitting shear loads at a common faying surface. Slip-critical joints shall be checked for slip resistance. At the option of the Engineer of Record, the required check may be based upon either nominal loads or factored loads. When serviceability at the nominal (service) load is the design criterion, the design slip resistance specified in Section 5(b) shall be compared with the effects of the nominal loads. When slip of the joint at the factored load level would affect the ability of the structure to support the factored load, the design slip resistance specified in Section 5(c) shall be compared to the effects of the factored loads.

Slip-critical joints shall also be checked to ensure that the ultimate strength of the joint as a bearing joint is equal to or greater than the effect of the factored loads.

Slip-critical joints must be designated on the contract plans and in the specifications. Bolts used in slip-critical joints shall be installed in accordance with the provisions of Section 8(d).

(b) Slip-Critical Joints Designed at the Nominal Load Level. Slip-critical joints for which nominal loads are the design criterion shall, in addition to meeting the requirements of Section 4, be proportioned so that the force due to nominal (service) loads does not exceed the design slip resistance for use at nominal loads (service) loads, ϕR_s, where:

$$R_s = D\mu T_m N_b N_s \qquad \text{(LRFD 5.1)}$$

Where:
R_s = nominal slip resistance of a bolt for use at nominal loads, kips
T_m = minimum fastener tension given in Table 4, kips
N_b = number of bolts in the joint
N_s = number of slip planes
D = slip probability factor*
= 0.81 for μ equal to 0.33
= 0.86 for μ equal to 0.40

= 0.86 for μ equal to 0.50

μ = mean slip coefficient for Class A, B or C surfaces,† as applicable, or as established by tests

= 0.33 for Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coating on blast-cleaned steel)

= 0.50 for Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

= 0.40 for Class C surfaces (hot-dip galvanized and roughened surfaces)

ϕ = 1.0 for standard holes

= 0.85 for oversize and short slotted holes

= 0.70 for long slotted holes transverse to the direction of load

= 0.60 for long slotted holes parallel to the direction of load

* *D* is a multiplier that reflects the distribution of actual slip coefficient values about the mean, the ratio of measured bolt tensile strength to the specified minimum values, and a slip probability level. Use of other values of *D* (see Commentary) must be approved by the Engineer of Record.

† Coatings classified as Class A or Class B includes those coatings which provide a mean slip coefficient not less than 0.33 or 0.50, respectively, as determined by "Test Method to Determine the Slip Coefficient for Coatings Used in Bolted Connections."

Table 4. Fastener Tension Required for Slip-Critical Connections and Connections Subject to Direct Tension

Nominal Bolt Size, Inches	Minimum Tension[a] in 1,000s of Pounds (kips)	
	A325 Bolts	A490 Bolts
½	12	15
⅝	19	24
¾	28	35
⅞	39	49
1	51	64
1⅛	56	80
1¼	71	102
1⅜	85	121
1½	103	148

a. Equal to 70 percent of specified minimum tensile strengths of bolts (as specified in ASTM Specifications for tests of full size A325 and A490 bolts with UNC threads loaded in axial tension) rounded to the nearest kip.

When using nominal loads as the basis for design of slip-critical connections subject to applied tension, *T*, that reduces the net clamping force, the slip resistance (ϕR_s) shall be multiplied by the following factor in which *T* is the applied tensile force at nominal loads

$$[1 - T/(0.82T_m N_b)] \qquad \text{(LRFD 5.2)}$$

(c) Slip-Critical Joints Designed at Factored Load Level. Slip-critical joints for which factored loads are the design criterion shall, in addition to meeting the requirements of Section 4, be proportioned so that the force due to the factored loads shall not exceed the design slip resistance for use at factored loads, ϕR_{str}, where:

$$R_{str} = 1.13\mu T_m N_b N_s \qquad \text{(LRFD 5.3)}$$

Where terms in Formula (LRFD 5.3) are as defined in 5(b).

When using factored loads as the basis for design of slip-critical connections subject to applied tension, T, that reduces the net clamping force, the slip resistance (ϕR_s) shall be multiplied by the following factor in which T is the applied tensile force at nominal loads

$$[1 - T/(1.13T_m N_b)] \qquad \text{(LRFD 5.4)}$$

6. Loads in Combination

When the reduced probabilities of maximum loads acting concurrently are accounted for by load combination factors, the resistances given in this Specification shall not be increased.

7. Design Details of Bolted Connections

(a) **Standard Holes.** In the absence of approval by the Engineer of Record for use of other hole types, standard holes shall be used in high-strength bolted connections.

(b) **Oversize and Slotted Holes.** When approved by the Engineer of Record, oversize holes, short slotted holes or long slotted holes may be used subject to the following joint detail requirements:

(1) Oversize holes may be used in all plies of connections in which the design slip resistance of the connection is greater than the factored nominal load.

(2) Short slotted holes may be used in any or all plies of connections in which the design strength (Section 4(a)) is greater than the factored nominal load provided the load is applied approximately normal (between 80 and 100 degrees) to the axis of the slot. Short slotted holes may be used without regard for the direction of applied load in any or all plies of connections in which the design slip resistance (Section 5(b)) is greater than the factored nominal load.

(3) Long slotted holes may be used in one of the connected parts at any individual faying surface in connections in which the design strength (Section 4(a)) is greater than the factored nominal load provided the load is applied approximately normal (between 80 and 100 degrees) to the axis of the slot. Long slotted holes may be used in one of the connected parts at any individual faying surface without regard for the direction of applied load on connections in which the design slip resistance (Section 5(b)) is greater than the factored nominal load.

(4) Fully inserted finger shims between the faying surfaces of load transmitting elements of connections are not to be considered a long slot element of a connection.

(c) **Washer Requirements.** Design details shall provide for washers in high-strength bolted connections as follows:

(1) Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, a hardened beveled washer shall be used to compensate for the lack of parallelism.

(2) Hardened washers are not required for connections using A325 and A490 bolts except as required in paragraphs 7(c)(3) through 7(c)(7) for slip-critical connections and connections subject to direct tension or as required by paragraph 8(c) for shear/bearing connections.
(3) Hardened washers shall be used under the element turned in tightening when the tightening is to be performed by calibrated wrench method.
(4) Irrespective of the tightening method, hardened washers shall be used under both the head and the nut when A490 bolts are to be installed and tightened to the tension specified in Table 4 in material having a specified yield point less than 40 ksi.
(5) Where A325 bolts of any diameter or A490 bolts equal to or less than 1 inch in diameter are to be installed and tightened in an oversize or short slotted hole in an outer ply, a hardened washer conforming to ASTM F436 shall be used.
(6) When A490 bolts over 1 inch in diameter are to be installed and tightened in an oversize or short slotted hole in an outer ply, hardened washers conforming to ASTM F436 except with $\frac{5}{16}$ inch minimum thickness shall be used under both the head and the nut in lieu of standard thickness hardened washers. Multiple hardened washers with combined thickness equal to or greater than $\frac{5}{16}$ inch do not satisfy this requirement.
(7) Where A325 bolts of any diameter or A490 bolts equal to or less than 1 inch in diameter are to be installed and tightened in a long slotted hole in an outer ply, a plate washer or continuous bar of at least $\frac{5}{16}$ inch thickness with standard holes shall be provided. These washers or bars shall have a size sufficient to completely cover the slot after installation and shall be of structural grade material, but need not be hardened except as follows. When A490 bolts over 1 inch in diameter are to be used in long slotted holes in external plies, a single hardened washer conforming to ASTM F436 but with $\frac{5}{16}$ inch minimum thickness shall be used in lieu of washers or bars of structural grade material. Multiple hardened washers with combined thickness equal to or greater than $\frac{5}{16}$ inch do not satisfy this requirement.
(8) Alternative design fasteners meeting the requirements of 2(d) with a geometry which provides a bearing circle on the head or nut with a diameter equal to or greater than the diameter of hardened washers meeting the requirements ASTM F436 satisfy the requirements for washers specified in paragraphs 7(c)(4) and 7(c)(5).

8. Installation and Tightening

(a) Handling and Storage of Fasteners. Fasteners shall be protected from dirt and moisture at the job site. Only as many fasteners as are anticipated to be installed and tightened during a work shift shall be taken from protected storage. Fasteners not used shall be returned to protected storage at the end of the shift. Fasteners shall not be cleaned of lubricant that is present in as-delivered condition. Fasteners which accumulate rust or dirt resulting from job site conditions shall be cleaned and relubricated prior to installation.

(b) Tension Calibrator. A tension measuring device shall be at all job sites where bolts in slip-critical joints or connections subject to direct tension are being installed and tightened. The tension measuring device shall be used to confirm (1) the suitability of the complete fastener assembly and method of tightening, including lubrication, if required to satisfy the requirements of Table 4, (2) to calibrate the wrenches, if applicable, and (3) to confirm the understanding and proper use by the bolting crew of the method to be used. The frequency of confirmation testing, the number of tests to be performed, and the test procedure shall be as specified in 8(d), as applicable. The accuracy of the tension measuring device shall be confirmed through calibration by an approved testing agency at least annually.

(c) Joint Assembly and Tightening of Shear/Bearing Connections.

(1) Snug Tightened Bolts. Bolts in connections not within the slip-critical category as defined in Section 5(a) nor subject to tension loads nor required to be pretensioned bearing connections in accordance with 8(c)(2) shall be installed in properly aligned holes, but need only be tightened to the snug tight condition. The snug tight condition is defined as the tightness that exists when all plies in a joint are in firm contact. (See Commentary.) If a slotted hole occurs in an outer ply, a flat hardened washer or common plate washer shall be installed over the slot.

(2) Tensioned Shear/Bearing Connections. The Engineer of Record may designate certain shear/bearing connections to be tightened to pretension in excess of snug tight. When so designated and identified on the contract drawings, the bolts in such connections shall be installed and tightened in accordance with one of the methods described in Subsections 8(d)(1) through 8(d)(4), but shall not be subject to the requirements for faying surface conditions of slip-critical connections contained in 3(b). The bolts need not be subject to inspection testing to determine the actual level of bolt pretension unless required by the Engineer of Record.

(d) Joint Assembly and Tightening of Slip-Critical and Direct Tension Connections. In slip-critical connections and connections subject to direct tension, fasteners together with washers of size and quality specified, located as required by Section 7(c), shall be installed in properly aligned holes and tightened by any of the methods described in Subsections 8(d)(1) through 8(d)(4) to at least the minimum tension specified in Table 4 when all the fasteners are tight. Tightening may be done by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. Impact wrenches, if used, shall be of adequate capacity and sufficiently supplied with air to perform the required tightening of each bolt in approximately 10 seconds. Slip-critical connections and connections subject to direct tension shall be clearly identified on the drawings.

(1) Turn-of-Nut Tightening. When turn-of-nut tightening is used, hardened washers are not required except as may be specified in 7(c).

A representative sample of not less than three bolt and nut assemblies of each diameter, length, grade and lot to be used in the work shall be checked at the start of work in a device capable of indicating bolt tension. The test shall demonstrate that the method for estimating the snug tight condition and controlling the turns from snug tight to be used by the bolting crew develops a tension not less than 5 percent greater than the tension required by Table 4.

Bolts shall be installed in all holes of the connection and brought to a "snug tight" condition. Snug tight is defined as the tightness that exists when the plies of the joint are in firm contact. Snug tightening shall progress systematically from the most rigid part of the connection to the free edges until all bolts are simultaneously snug tight and the connection is fully compacted. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic tightening to produce a uniform snug tight condition. Following this initial operation, all bolts in the connection shall be tightened further by application of the rotation specified in Table 5. During the tightening operation, there shall be no rotation of the part not turned by the wrench. Tightening shall progress systematically from the most rigid part of the joint to its free edges.

(2) **Calibrated Wrench Tightening:** Calibrated wrench tightening may be used only when installation procedures are calibrated on a daily basis and when a hardened washer is used under the element turned in tightening. (See the Commentary to this Section.) This specification does not recognize standard torques determined from tables or from formulas which are assumed to relate torque to tension.

When calibrated wrenches are used for installation, they shall be set to provide a tension not less than 5 percent in excess of the minimum tension specified in Table 4. The installation procedures shall be calibrated at least once each working day by tightening representative sample fastener assemblies in a device capable of indicating actual bolt tension. The representative fastener assemblies shall consist of three bolts from each lot, diameter, length and grade with nuts from each lot, diameter and grade and with a hardened washer from the washers being used in the work under the element turned in tightening. Wrenches shall be recalibrated when significant difference is noted in the surface condition of the bolts' threads, nuts or washers. It shall be verified during actual installation in the assembled steelwork that the wrench adjustment selected by the calibration does not produce a nut or bolt head rotation from snug tight greater than that permitted in Table 5. If manual torque wrenches are used, nuts shall be turned in the tightening direction when torque is measured.

When calibrated wrenches are used to install and tension bolts in a connection, bolts shall be installed with hardened washers under the element turned in tightening bolts in all holes of the connection and brought to a snug tight condition. Snug tightening shall progress systematically from the most rigid part of the connections to the free edges until bolts are uniformly snug tight and the plies of the joint are in firm contact. Following this initial tightening operation, the connection shall be tightened using the calibrated wrench. Tightening shall progress systematically from the most rigid part

Table 5. Nut Rotation from Snug Tight Condition[a,b]

Bolt length (underside of head to end of bolt)	Disposition of Outer Face of Bolted Parts		
	Both faces normal to bolt axis	One face normal to bolt axis and other sloped not more than 1:20 (beveled washer not used)	Both faces sloped not more than 1:20 from normal to the bolt axis (beveled washer not used)
Up to and including 4 diameters	⅓ turn	½ turn	⅔ turn
Over 4 diameters but not exceeding 8 dia.	½ turn	⅔ turn	⅚ turn
Over 8 diameters but not exceeding 12 dia.[c]	⅔ turn	⅚ turn	1 turn

a. Nut rotation is relative to bolt regardless of the element (nut or bolt) being turned. For bolts installed by ½ turn and less, the tolerance should be plus or minus 30 degrees; for bolts installed by ⅔ turn and more, the tolerance should be plus or minus 45 degrees.
b. Applicable only to connections in which all material within the grip of the bolt is steel.
c. No research has been performed by the Council to establish the turn-of-nut procedure for bolt lengths exceeding 12 diameters. Therefore, the required rotation must be determined by actual test in a suitable tension measuring device which simulates conditions of solidly fitted steel.

of the joint to its free edges. During snugging and final tightening the element not turned in tightening shall be held to prevent rotation which will damage threads. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic tightening to ensure all bolts are tightened to at least the prescribed amount.

(3) **Installation of Alternative Design Bolts.** When fasteners which incorporate a design feature intended to indicate a predetermined tension or torque has been applied or to control bolt installation tension or torque, and which have been qualified under Section 2(d) are to be installed, a representative sample of not less than three bolts of each diameter, length and grade shall be checked at the job site in a device capable of indicating bolt tension. The test assembly shall include flat hardened washers, if required in the actual connection, arranged as in the actual connections to be tensioned. The calibration test shall demonstrate that each bolt develops a tension not less than 5 percent greater than the tension required by Table 4. Manufacturer's installation procedure as required by Section 2(d) shall be followed for installation of bolts in the calibration device and in all connections.

When alternative design fasteners are used in the work, bolts shall be installed in all holes of the connection and initially tightened sufficiently to bring all plies of the joint into firm contact with the bolts uniformly tight but without yielding or fracturing the control or indicator element of the fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening. After all plies of the joint are in firm contact, all fasteners shall be further tightened, progressing systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final yielding or fracture of the control or indicator element of individual fasteners.

(4) Direct Tension Indicator Tightening. When bolts are to be installed using direct tension indicator devices to indicate bolt tension, a representative sample of not less than three devices for each diameter and grade of fastener shall be tested with three typical bolts in a calibration device capable of indicating bolt tension. The test assembly shall include flat hardened washers, if required in the actual connection, arranged as those in the actual connections to be tensioned. The calibration test shall demonstrate that the device indicates a tension not less than 5 percent greater than that required by Table 4.

When bolts are installed in the work using direct tension indicators meeting the requirements of ASTM F959, bolts shall be installed in all holes of the connection and tightened until all plies of the joint are in firm contact and fasteners are uniformly snug tight. Snug tight is indicated by partial compression of the direct tension indicator protrusions. All fasteners shall then be tightened, progressing systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. In some cases, proper tensioning of the bolts may require more than a single cycle of systematic partial tightening prior to final tightening to deform the protrusion to the specified gap.

Special attention shall be given to proper installation of flat hardened washers when direct tension indicator devices are used with bolts installed in oversize or slotted holes and when the load indicating devices are used under the turned element.

If direct tension indicators different from those meeting the requirements of ASTM F959 are used, manufacturer's installation procedure as required by Section 2(f), shall be followed for installation of bolts in the calibration device and in all connections, and in addition the general requirements for use of direct tension indicators meeting the requirements of ASTM F959 shall be met.

(e) Identification of Tightening Requirements. Bolts in slip-critical connections or bolts subject to axial tension which are to be installed and tightened in accordance by one of the methods in 8(d) and which require inspection to ensure that requirements of Table 4 are satisfied shall be clearly identified on the contract drawings. Shear/bearing connections which are to be installed by one of the methods in 8(d) but which need not be inspected to ensure bolt tensions specified in Table 4 are met shall be clearly identified on the contract drawings.

(f) Reuse of Bolts. A490 bolts and galvanized A325 bolts shall not be reused. Other A325 bolts may be reused if approved by the Engineer of Record. Touching up or retightening previously snug tightened bolts which may have been loosened by the snugging of adjacent bolts shall not be considered to be a reuse.

9. Inspection

(a) Inspector Responsibility. When inspection is required by the contract documents, the Inspector shall determine while the work is in progress that the requirements of Sections 2, 3 and 8, as appropriate, of this Specification are met in the work. All connections shall be inspected to ensure that the plies of the connected elements have been brought into firm contact.

Bolts in connections not identified as being slip-critical nor subject to direct tension nor as tensioned bearing connections as provided in 8(c)(2) should not be inspected for bolt tension. For connections identified to be installed in accordance with 8(c)(2), the Inspector shall monitor installation and tightening of bolts to ensure that bolts are tightened in accordance with one of the methods of 8(d), but should not test the bolts for actual installed pretension.

For all connections specified to be slip critical or subject to axial tension, the Inspector shall observe the demonstration testing, and calibration procedures when such calibration is required, and shall monitor the installation of bolts to determine that all plies of the material have been drawn together and that the selected procedure has been used to tighten all bolts to ensure that the specified procedure was followed to achieve the pretension specified in Table 4. Bolts installed by procedures in Section 8(d) may reach tensions substantially greater than values given in Table 4, but this shall not be cause for rejection.

(b) Arbitration Inspection. When high-strength bolts in slip-critical connections and connections subject to direct tension have been installed by any of the tightening methods in Section 8(d) and inspected in accordance with Section 9(a) and a disagreement exists as to the minimum tension of the installed bolts, the following arbitration procedure may be used. Other methods for arbitration inspection may be used if approved by the Engineer of Record.

(1) The Inspector shall use a manual torque wrench which indicates torque by means of a dial or which may be adjusted to give an indication that the job inspecting torque has been reached.

(2) This Specification does not recognize standard torques determined from tables or from formulas which are assumed to relate torque to tension. Testing using such standard torques shall not be considered valid.

(3) A representative sample of five bolts from the diameter, length and grade of the bolts being inspected shall be tightened in the tension measuring device by any convenient means to an initial condition equal to approximately 15 percent of the required fastener tension and then to the minimum tension specified in Table 4. Material under the turned element in the tension measuring device shall be the same as in the actual installation, that is, structural steel or

hardened washer. Tightening beyond the initial condition must not produce greater nut rotation than 1½ times that permitted in Table 5. The job inspecting torque shall be taken as the average of three values thus determined after rejecting the high and low values. The inspecting wrench shall then be applied to the tightened bolts in the work and the torque necessary to turn the nut or head 5 degrees (approximately 1 inch at 12 inch radius) in the tightening direction shall be determined.

(4) Bolts represented by the sample in the foregoing paragraph which have been tightened in the structure shall be inspected by applying, in the tightening direction, the inspecting wrench and its job torque to 10 percent of the bolts, but not less than 2 bolts, selected at random in each connection in question. If no nut or bolt head is turned by application of the job inspecting torque, the connection shall be accepted as properly tightened. If any nut or bolt is turned by the application of the job inspecting torque, all bolts in the connection shall be tested, and all bolts whose nut or head is turned by the job inspecting torque shall be tightened and reinspected. Alternatively, the fabricator or erector, at his option, may retighten all of the bolts in the connection and then resubmit the connection for the specified inspection.

(c) Delayed Verification Inspection. The procedures specified in Sections 9(a) and (b) are intended for inspection of bolted connections and verification of pretension at the time of tensioning the joint. If verification of bolt tension is required after a passage of a period of time and exposure of the completed joints, the procedure of Section 9(b) will provide indication of bolt tension which is of questionable accuracy. Procedures appropriate to the specific situation should be used for verification of bolt tension. This might involve use of the arbitration inspection procedure contained herein, or might require the development and use of alternate procedures. (See Commentary.)

APPENDIX A

Testing Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints

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JOSEPH A. YURA and KARL H. FRANK

In 1975, the Steel Structures Painting Council (SSPC) contacted the Research Council on Riveted and Bolted Structural Joints (RCRBSJ), now the Research Council on Structural Connections (RCSC), regarding the difficulties and costs which steel fabricators encounter with restrictions on coatings of contact surfaces for friction-type structural joints. The SSPC also expressed the need for a "standardized test which can be conducted by any certified testing agency at the initiative and expense of any interested party, including the paint manufacturer." And finally, the RCSC was requested to "prepare and promulgate a specification for the conduct of such a standard test for slip coefficients."

The following Testing Method is the answer of Research Council on Structural Connections to the SSPC request. The test method was developed by Professors Joseph A. Yura and Karl H. Frank of the University of Texas at Austin under a grant from the Federal Highway Administration. The Testing Method was approved by the RCSC on June 14, 1984.

1.0 GENERAL PROVISIONS

1.1 Purpose and Scope

The purpose of the testing procedure is to determine the slip coefficient of a coating for use in high-strength bolted connections. The testing specification ensures that the creep deformation of the coating due to both the clamping force of the bolt and the service load joint shear are such that the coating will provide satisfactory performance under sustained loading.

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1.2 Definition of Essential Variables

Essential variables mean those variables which, if changed, will require retesting of the coating to determine its slip coefficient. The essential variables are given below. The relationship of these variables to the limitation of application of the coating for structural joints is also given.

The *time interval* between application of the coating and the time of testing is an essential variable. The time interval must be recorded in hours and any special curing procedures detailed. Curing according to published manufacturer's recommendations would not be considered a special curing procedure. The coatings are qualified for use in structural connections which are assembled after coating for a time equal to or greater than the interval used in the test specimens. Special curing conditions used in the test specimens will also apply to the use of the coating in the structural connections.

The *coating thickness* is an essential variable. The maximum average coating thickness allowed on the bolted structure will be the average thickness, rounded to the nearest whole mil, of the coating used on the creep test specimens minus 2 mils.

The *composition of the coating,* including the thinners used, and its method of manufacture are essential variables. Any change will require retesting of the coating.

1.3 Retesting

A coating which fails to meet the creep or the post-creep slip test requirements given in Sect. 4 may be retested in accordance with methods in Sect. 4 at a lower slip coefficient, without repeating the static short-term tests specified in Sect. 3. Essential variables must remain unchanged in the retest.

2.0 TEST PLATES AND COATING OF THE SPECIMENS

2.1 Test Plates

The test specimen plates for the short-term static tests are shown in Fig. 1. The plates are 4×4 in. plates, ⅝-in. thick, with a 1-in. dia. hole drilled 1½ in. ± $\frac{1}{16}$ in. from one edge. The specimen plates for the creep specimen are shown in Fig. 2. The plates are 4×7 in., ⅝-in. thick, with two 1-in. holes, 1½ in. ± $\frac{1}{16}$ in. from each end. The edges of the plates may be milled, as rolled or saw cut. Flame cut edges

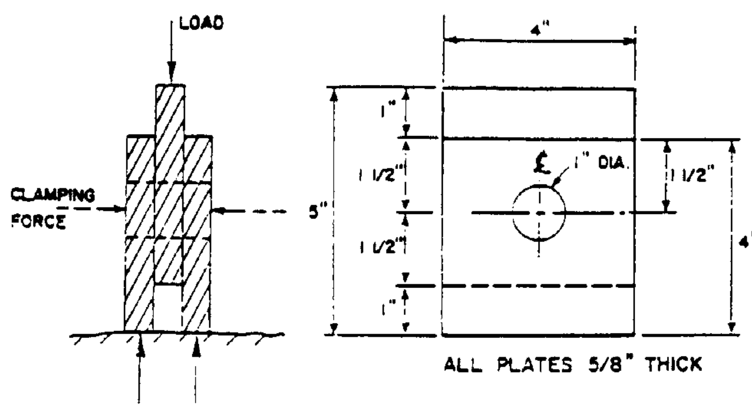

Fig. 1. Compression test specimen

are not permitted. The plates should be flat enough to ensure they will be in reasonably full contact over the faying surface. Any burrs, lips or rough edges should be filed or milled flat. The arrangement of the specimen plates for the testing is shown in Figs. 2 and 3. The plates are to be fabricated from a steel with a minimum yield strength between 36 to 50 ksi.

If specimens with more than one bolt are desired, the contact surface per bolt should be 4×3 in. as shown for the single bolt specimen in Fig. 1.

2.2 Specimen Coating

The coatings are to be applied to the specimens in a manner consistent with the actual intended structural application. The method of applying the coating and the surface preparation should be given in the test report. The specimens are to be coated to an average thickness 2 mils (0.05 mm) greater than average thickness to be used in the structure. The thickness of the total coating and the primer, if used, shall be measured on the contact surface of the specimens. The thickness should be measured in accordance with the Steel Structures Painting Council specification SSPC-PA2, Measurement of Dry Paint Thickness with Magnetic Gages.[1] Two spot readings (six gage readings) should be made for each contact surface. The overall average thickness from the three plates comprising a specimen is the average thickness for the specimen. This value should be reported for each specimen. The average coating thickness of the three creep specimens will be calculated and reported. The average thickness of the creep specimen minus two mils rounded to the nearest whole mil is the maximum average thickness of the coating to be used in the faying surface of a structure.

The time between painting and specimen assembly is to be the same for all specimens within ±4 hours. The average time is to be calculated and reported. The two coating applications required in Sect. 3 are to use the same equipment and procedures.

3.0 SLIP TESTS

The methods and procedures described herein are used to determine experimentally the slip coefficient (sometimes called the coefficient of friction) under short-term static loading for high-strength bolted connections. The slip coefficient will be determined by testing two sets of five specimens. The two sets are to be coated at different times at least one week apart.

3.1 Compression Test Setup

The test setup shown in Fig. 3 has two major loading components, one to apply a clamping force to the specimen plates and another to apply a compressive load to the specimen so that the load is transferred across the faying surfaces by friction.

Clamping Force System. The clamping force system consists of a ⅞-in. dia. threaded rod which passes through the specimen and a centerhole compression ram. A 2H nut is used at both ends of the rod, and a hardened washer is used at each side of the test specimen. Between the ram and the specimen is a specially fabricated ⅞-in. 2H nut in which the threads have been drilled out so that it will slide with little resistance along the rod. When oil is pumped into the centerhole ram,

1. Steel Structures Painting Council, *Steel Structures Painting Manual*, Vols. 1 and 2. Pittsburgh, Pa., 1982.

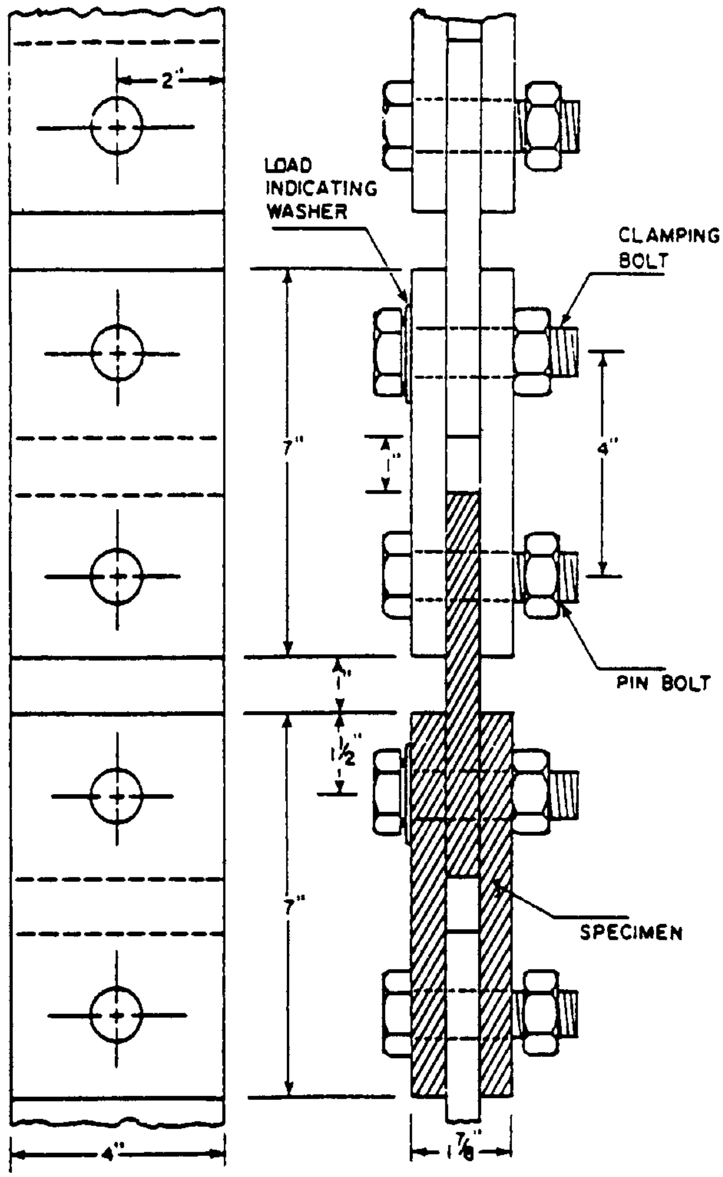

Fig. 2. Creep test specimens

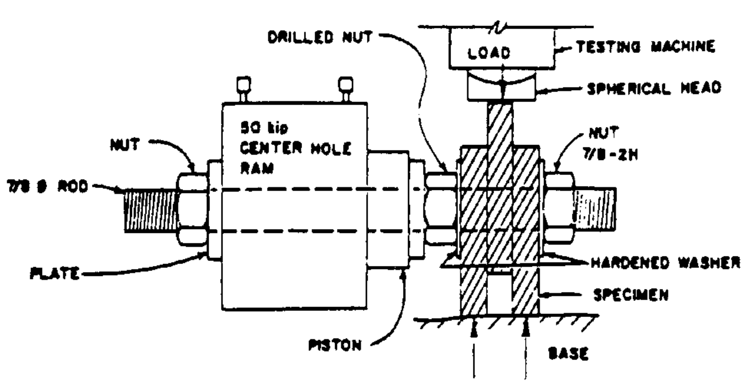

Fig. 3. Test setup

the piston rod extends, thus forcing the special nut against one of the outside plates of the specimen. This action puts tension in the threaded rod and applies a clamping force to the specimen which simulates the effect of a tightened bolt. If the diameter of the centerhole ram is greater than 1 in., additional plate washers will be necessary at the ends of the ram. The clamping force system must have a capability to apply a load of at least 49 kips and maintain this load during the test with an accuracy of ±1%.

Compressive Load System. A compressive load is applied to the specimen until slip occurs. This compressive load can be applied by a compression test machine or compression ram. The machine, ram and the necessary supporting elements should be able to support a force of 90 kips.

The compression loading system should have an accuracy of 1.0% of the slip load.

3.2 Instrumentation

Clamping Force. The clamping force must be measured within 0.5 kips. This may be accomplished by measuring the pressure in the calibrated ram or placing a load cell in series with the ram.

Compression Load. The compression load must be measured during the test. This may be accomplished by direct reading from a compression testing machine, a load cell in series with the specimen and the compression loading device, or pressure readings on a calibrated compression ram.

Slip Deformation. The relative displacement of the center plate and the two outside plates must be measured. This displacement, called slip for simplicity, should be the average which occurs at the centerline of the specimen. This can be accomplished by using the average of two gages placed on the two exposed edges of the specimen or by monitoring the movement of the loading head relative to the base. If the latter method is used, due regard must be taken for any slack that may be present in the loading system prior to application of the load. Deflections can be measured by dial gages or any other calibrated device which has an accuracy of 0.001 in.

3.3 Test Procedure

The specimen is installed in the test setup as shown in Fig. 3. Before the hydraulic clamping force is applied, the individual plates should be positioned so that they are in, or are close to, bearing contact with the ⅞-in. threaded rod in a direction opposite to the planned compressive loading to ensure obvious slip deformation. Care should be taken in positioning the two outside plates so that the specimen will be straight and both plates are in contact with the base.

After the plates are positioned, the centerhold ram is engaged to produce a clamping force of 49 kips. The applied clamping force should be maintained within ±0.5 kips during the test until slip occurs.

The spherical head of the compression loading machine should be brought in contact with the center plate of the specimen after the clamping force is applied. The spherical head or other appropriate device ensures uniform contact along the edge of the plate, thus eliminating eccentric loading. When 1 kip or less of compressive load is applied, the slip gages should be engaged or attached. The purpose of engaging the deflection gage(s), after a slight load is applied, is to eliminate initial specimen settling deformation from the slip readings.

When the slip gages are in place, the compression load is applied at a rate not exceeding 25 kips (109 kN) per minute, or 0.003 in. of slip displacement per minute until the slip load is reached. The test should be terminated when a slip of 0.05 in. or greater is recorded. The load-slip relationship should preferably be monitored continuously on an X-Y plotter throughout the test, but in lieu of continuous data, sufficient load-slip data must be recorded to evaluate the slip load defined below.

3.4 Slip Load

Typical load-slip response is shown in Fig. 4. Three types of curves are usually observed and the slip load associated with each type is defined as follows:

Curve (a). Slip load is the maximum load, provided this maximum occurs before a slip of 0.02 in. is recorded.

Curve (b). Slip load is the load at which the slip rate increases suddenly.

Curve (c). Slip load is the load corresponding to a deformation of 0.02 in. This definition applies when the load vs. slip curves show a gradual change in response.

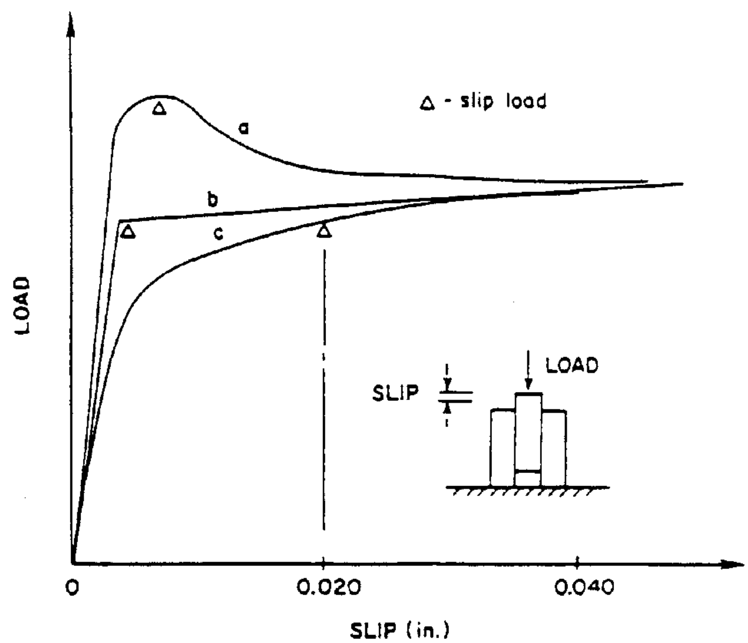

Fig. 4. Definition of slip load

3.5 Coefficient of Slip

The slip coefficient k_s for an individual specimen is calculated as follows:

$$k_s = \frac{\text{slip load}}{2 \times \text{clamping force}}$$

The mean slip coefficient for both sets of five specimens must be compared. If the two means differ by more than 25%, using the smaller mean as the base, a third five-specimen set must be tested. The mean and standard deviation of the data from all specimens tested define the slip coefficient of the coating.

3.6 Alternate Test Methods

Other test methods to determine slip may be used provided the accuracy of load measurement and clamping satisfies the conditions presented in the previous sections. For example, the slip load may be determined from a tension-type test setup rather than the compression-type as long as the contact surface area per fastener of the test specimen is the same as shown in Fig. 1. The clamping force of at least 49 kips may be applied by any means provided the force can be established within ±1%. Strain-gaged bolts can usually provide the desired accuracy. However, bolts installed by turn-of-nut method, tension indicating fasteners and load indicator washers usually show too much variation to be used in the slip test.

4.0 TENSION CREEP TESTS

The test method outlined is intended to ensure the coating will not undergo significant creep deformation under service loading. The test also determines the loss in clamping force in the fastener due to the compression or creep of the paint. Three replicate specimens are to be tested.

4.1 Test Setup

Tension-type specimens, as shown in Fig. 2, are to be used. The replicate specimens are to be linked together in a single chain-like arrangement, using loose pin bolts, so the same load is applied to all specimens. The specimens shall be assembled so the specimen plates are bearing against the bolt in a direction opposite to the applied tension loading. Care should be taken in the assembly of the specimens to ensure the centerline of the holes used to accept the pin bolts is in line with the bolts used to assemble the joint. The load level, specified in Sect. 4.2, shall be maintained constant within ±1% by springs, load maintainers, servo controllers, dead weights or other suitable equipment. The bolts used to clamp the specimens together shall be ⅞-in. dia. A490 bolts. All bolts should come from the same lot.

The clamping force in the bolts should be a minimum of 49 kips. The clamping force is to be determined by calibrating the bolt force with bolt elongation, if standard bolts are used. Special fasteners which control the clamping force by other means such as bolt torque or strain gages may be used. A minimum of three bolt calibrations must be performed using the technique selected for bolt force determination. The average of the three-bolt calibration is to be calculated and reported. The method of measuring bolt force must ensure the clamping force is within ±2 kips (9 kN) of the average value.

The relative slip between the outside plates and the center plates shall be measured to an accuracy of 0.001 in. (0.02 mm). This is to be measured on both sides of each specimen.

4.2 Test Procedure

The load to be placed on the creep specimens is the service load permitted for ⅞-in. A490 bolts in slip-critical connections by the latest edition of the *Specification for Structural Joints Using ASTM A325 or A490 Bolts*[2] for the particular slip coefficient category under consideration. The load is to be placed on the specimen and held

2. Research Council on Structural Connections, *Specification for Structural Joints Using ASTM A325 or A490 Bolts*, American Institute of Steel Construction, Inc., Chicago, November 1985.

for 1,000 hours. The creep deformation of a specimen is calculated using the average reading of the two displacements on each side of the specimen. The difference between the average after 1,000 hours and the initial average reading taken within one-half hour after loading the specimens is defined as the creep deformation of the specimen. This value is to be reported for each specimen. If the creep deformation of any specimen exceeds 0.005 in. (0.12 mm), the coating has failed the test for the slip coefficient used. The coating may be retested using new specimens in accordance with this section at a load corresponding to a lower value of slip coefficient.

If the value of creep deformation is less than 0.005 in. (0.12 mm) for all specimens, the specimens are to be loaded in tension to a load calculated as

$$P_u = \text{average clamping force} \times \text{design slip coefficient} \times 2$$

since there are two slip planes. The average slip deformation which occurs at this load must be less than 0.015 in. (0.38 mm) for the three specimens. If the deformation is greater than this value, the coating is considered to have failed to meet the requirements for the particular slip coefficient used. The value of deformation for each specimen is to be reported.

COMMENTARY

The slip coefficient under short-term static loading has been found to be independent of clamping force, paint thickness and hole diameter.[3] The slip coefficient can be easily determined using the hydraulic bolt test setup included in this specification. The slip load measured in this setup yields the slip coefficient directly since the clamping force is controlled. The slip coefficient k_s is given by

$$k_s = \frac{\text{slip load}}{2 \times \text{clamping force}}$$

The resulting slip coefficient has been found to correlate with both tension and compression tests of bolted specimens. However, tests of bolted specimens revealed that the clamping force may not be constant but decreases with time due to the compressive creep of the coating on the faying surfaces and under the nut and bolt head. The reduction of the clamping force can be considerable for joints with high clamping force and thick coatings, as much as a 20% loss. This reduction in clamping force causes a corresponding reduction in the slip load. The resulting reduction in slip load must be considered in the procedure used to determine the design allowable slip loads for the coating.

The loss in clamping force is a characteristic of the coating. Consequently, it cannot be accounted for by an increase in the factor of safety or a reduction in the clamping force used for design without unduly penalizing coatings which do not exhibit this behavior.

The creep deformation of the bolted joint under the applied shear loading is also an important characteristic and a function of the coating applied. Thicker coatings tend to creep more than thinner coatings. Rate of creep deformation increases as the applied load approaches the slip load. Extensive testing has shown the rate of creep is not constant with time, rather it decreases with time. After 1,000 hours of loading, the additional creep deformation is negligible.

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3. Frank, K. H., and J. A. Yura, *An Experimental Study of Bolted Shear Connections*, FHWA/RD-81-148, Federal Highway Administration, Washington, D.C., December 1981.

The proposed test methods are designed to provide the necessary information to evaluate the suitability of a coating for slip critical bolted connections and to determine the slip coefficient to be used in the design of the connections. The initial testing of the compression specimens provides a measure of the scatter of the slip coefficient. In order to get better statistical information, a third set of specimens must be tested whenever the means of the initial two sets differ by more than 25%.

The creep tests are designed to measure the paint's creep behavior under the service loads determined by the paint's slip coefficient based on the compression test results. The slip test conducted at the conclusion of the creep test is to ensure the loss of clamping force in the bolt does not reduce the slip load below that associated with the design slip coefficient. A490 bolts are specified, since the loss of clamping force is larger for these bolts than A325 bolts. Qualifying of the paint for use in a structure at an average thickness of 2 mils less than the test specimen is to ensure that a casual buildup of paint due to overspray, etc., does not jeopardize the coating's performance.

The use of 1-in. (25 mm) holes in the specimens is to ensure that adequate clearance is available for slip. Fabrication tolerances, coating buildup on the holes and assembly tolerances reduce the apparent clearances.

Commentary on Specifications for Structural Joints Using ASTM A325 or A490 Bolts

June 8, 1988.

Historical Notes

When first approved by the Research Council on Structural Connections of the Engineering Foundation, January 1951, the "Specification for Assembly of Structural Joints Using High-Strength Bolts" merely permitted the substitution of a like number of A325 high-strength bolts for hot driven ASTM A141 (presently identified as A502, Grade 1) steel rivets of the same nominal diameter. It was required that all contact surfaces be free of paint. As revised in 1954, the omission of paint was required to apply only to "joints subject to stress reversal, impact or vibration, or to cases where stress redistribution due to joint slippage would be undesirable." This relaxation of the earlier provision recognized the fact that, in a great many cases, movement of the connected parts that brings the bolts into bearing against the sides of their holes is in no way detrimental.

In the first edition of the Specification published in 1951, a table of torque to tension relationships for bolts of various diameters was included. It was soon demonstrated in research that a variation in the torque to tension relationship of as high as plus or minus 40 percent must be anticipated unless the relationship is established individually for each bolt lot, diameter and fastener condition. Hence, by the 1954 edition of the Specification, recognition of standard torque to tension relationships in the form of tabulated values or formulas was withdrawn. Recognition of the calibrated wrench method of tightening was retained, however, until 1980, but with the requirement that the torque required for installation or inspection be determined specifically for the bolts being installed on a daily basis. Recognition of the method was withdrawn in 1980 because of continuing controversy resulting from failure of users to adhere to the detailed requirements for valid use of the method both during installation and inspection. With the 1985 version of the Specification, the calibrated wrench method was reinstated, but with more detailed requirements which should be carefully followed.

The increasing use of high-strength steels created the need for bolts substantially stronger than A325 in order to resist the much greater forces they support without resort to very large connections. To meet this need, a new ASTM specification, A490, was developed. When provisions for the use of these bolts were included in this Specification in 1964, it was required that they be tightened to their specified proof load, as was required for the installation of A325 bolts. However, the ratio of proof load to specified minimum tensile strength is approximately 0.7 for A325 bolts, whereas it is 0.8 for A490 bolts. Calibration studies have shown that high-strength bolts have ultimate load capacities in torqued tension which vary from about

80 to 90 percent of the pure-tension tensile strength.[1] Hence, if minimum strength A490 bolts were supplied and they experienced the maximum reduction due to torque required to induce the tension, there is a possibility that these bolts could not be tightened to proof load by any method of installation. Also, statistical studies have shown that tightening to the 0.8 times tensile strength under calibrated wrench control may result in some "twist-off" bolt failures during installation or in some cases a slight amount of under-tightening.[2] Therefore, the required installed tension for A490 bolts was reduced to 70 percent of the specified minimum tensile strength. For consistency, but with only minor change, the initial tension required for A325 bolts was also set at 70 percent of their specified minimum tensile strength and, at the same time, the values for minimum required pretension were rounded off to the nearest kip.

C1 Scope

This Specification deals only with two types of high-strength bolts, namely, ASTM A325 and A490, and to their installation in structural steel joints. The provisions may not be relied upon for high-strength fasteners of other chemical composition or mechanical properties or size. The provisions do not apply to ASTM A325 or A490 fasteners when material other than steel is included in the grip. The provisions do not apply to high-strength anchor bolts.

The Specification relates only to the performance of fasteners in structural steel connections and those few aspects of the connected material that affect the performance of the fasteners in connections. Many other aspects of connection design and fabrication are of equal importance and must not be overlooked. For information on questions of design of connected material, not covered herein, the user is directed to standard textbooks on design of structural steel and also to Kulak, G. L., J. W. Fisher, and J. H. A. Struik, *Guide to Design Criteria for Bolted and Riveted Joints,* 2nd ed., New York: John Wiley & Sons, 1987. (Hereinafter referred to as the *Guide.*)

C2 Bolts, Nuts, Washers and Paint

Complete familiarity with the referenced ASTM Specification requirements is necessary for the proper application of this Specification. Discussion of referenced specifications in this Commentary is limited to only a few frequently overlooked or little-understood items.

In this Specification, a single style of fastener (heavy hex structural bolts with heavy hex nuts) available in two strength grades (A325 and A490) is specified as a principal style, but conditions for acceptance of other types of fasteners are provided.

Bolt Specifications. ASTM A325 and A490 bolts are manufactured to dimensions as specified in ANSI Standard B18.2.1 for Heavy Hex Structural Bolts. The basic dimensions, as defined in Fig. C1, are shown in Table C1. 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 body length. The head of the heavy hex

1. Christopher, R. J., G. L. Kulak, and J. W. Fisher, "Calibration of Alloy Steel Bolts," ASCE *Journal of the Structural Division,* Vol. 92, No. ST2, Proc. Paper 4768, April, 1966, pp. 19–40.
2. Gill, P. J., "Specifications of Minimum Preloads for Structural Bolts," Memorandum 30, G.K.N. Group Research Laboratory, England, 1966 (Unpublished Report).

Table C1

Nominal Bolt Size, Inches D	Bolt Dimensions, Inches Heavy Hex Structural Bolts			Nut Dimensions, Inches Heavy Hex nuts	
	Width across flats, F	Height H	Thread length	Width across flats, W	Height H
1/2	7/8	5/16	1	7/8	31/64
5/8	1 1/16	25/64	1 1/4	1 1/16	39/64
3/4	1 1/4	15/32	1 3/8	1 1/4	47/64
7/8	1 7/16	35/64	1 1/2	1 7/16	55/64
1	1 5/8	39/64	1 3/4	1 5/8	64/64
1 1/8	1 13/16	11/16	2	1 13/16	1 7/64
1 1/4	2	25/32	2	2	1 7/32
1 3/8	2 3/16	27/32	2 1/4	2 3/16	1 11/32
1 1/2	2 3/8	15/16	2 1/4	2 3/8	1 15/32

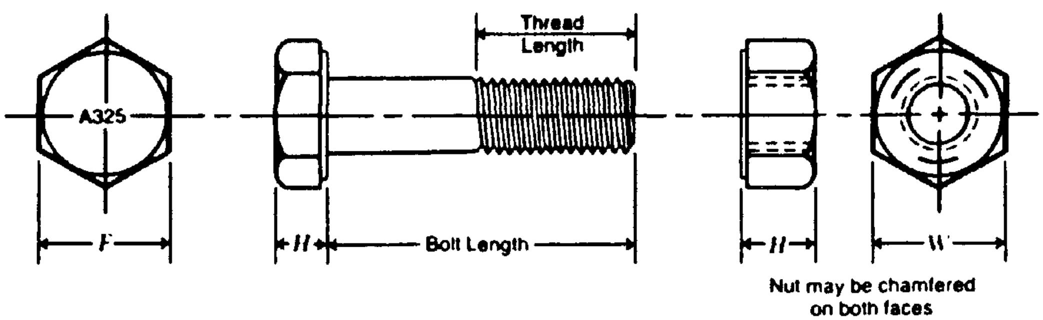

Fig. C1. Heavy hex structural bolt and heavy hex nut

structural bolt is specified to be the same size as a heavy hex nut of the same nominal diameter in order that the ironworker may use a single size wrench or socket on both the bolt head and the nut. Heavy hex structural bolts have shorter thread length than bolts for general application. By making the body length of the bolt the control dimension, it has been possible to exclude the thread from all shear planes, except in the case of thin outside parts adjacent to the nut. Depending upon the amount of bolt length added to adjust for incremental stock lengths, the full thread may extend into the grip by as much as 3/8 inch for 1/2, 5/8, 3/4, 7/8, 1 1/4, and 1 1/2 in. diameter bolts and as much as 1/2 inch for 1, 1 1/8 and 1 3/8 in. diameter bolts. Inclusion of some thread run-out in the plane of shear is permissible. Of equal or even greater importance is exercise of care to provide sufficient thread for nut tightening to keep the nut threads from jamming into the thread run-out. When the thickness of an outside part is less than the amount the threads may extend into the grip tabulated above, it may be necessary to call for the next increment of bolt length together with sufficient flat washers to ensure full tightening of the nut without jamming nut threads on the thread run-out.

There is an exception to the short thread length requirements for ASTM A325 bolts discussed in the foregoing. Beginning with ASTM A325-83, supplementary requirements have been added to the ASTM A325 Specification which permit the purchaser, when the bolt length is equal to or shorter than four times the nominal diameter, to specify that the bolt be threaded for the full length of the shank. This exception to the requirements for thread length of heavy hex structural bolts was provided in the Specification in order to increase economy through simplified ordering and inventory control in the fabrication and erection of structures using relatively thin materials where strength of the connection is not dependent upon shear strength of the bolt, whether threads are in the shear plane or not. The Specification requires that bolts ordered to such supplementary requirements be marked with the symbol A325T.

In order to determine the required bolt length, the value shown in Table C2 should be added to the grip (i.e., the total thickness of all connected material, exclusive of washers). For each hardened flat washer that is used, add 5/32 inch, and for each beveled washer add 5/16 inch. The tabulated values provide appropriate allowances for manufacturing tolerances, and also provide for full thread engagement (defined as having the end of the bolt at least flush with the face of the nut) with an installed heavy hex nut. The length determined by the use of Table C2 should be adjusted to the next longer ¼ inch length.

ASTM A325 and ASTM A490 currently provide for three types (according to metallurgical classification) of high-strength structural bolts, supplied in sizes ½ inch to 1½ inch inclusive except for A490 Type 2 bolts which are available in diameters from ½ inch to 1 inch inclusive:

Type 1. Medium carbon steel for A325 bolts, alloy steel for A490 bolts.
Type 2. Low carbon martensitic steel for both A325 and A490 bolts.
Type 3. Bolts having improved atmospheric corrosion resistance and weathering characteristics for both A325 and A490 bolts.

When the bolt type is not specified, either Type 1, Type 2 or Type 3 may be supplied at the option of the manufacturer. Special attention is called to the requirement in ASTM A325 that, where elevated temperature applications are involved, Type 1 bolts shall be specified by the purchaser. This is because the chemistry of Type 2 bolts permits heat treatment at sufficiently low temperatures that subsequent heating to elevated temperatures may affect the mechanical properties.

Heavy Hex Nuts. Heavy hex nuts for use with A325 bolts may be manufactured to the requirements of ASTM A194 for grades 2 or 2H or the requirements of ASTM A563 for grades DH, except that nuts to be galvanized for use with galvanized bolts must be hardened nuts meeting the requirements for ASTM A563 grade DH.

The heavy hex nuts for use with A490 bolts may be manufactured to the requirements of ASTM A194 for grade 2H or the requirements of ASTM A563 for grade DH.

Galvanized High-Strength Bolts. Galvanized high-strength bolts and nuts must be considered as a manufactured matched assembly; hence, comments relative to them have not been included in the foregoing paragraphs where bolts and nuts have been considered separately. Insofar as the hot-dip galvanized bolt and nut assembly, per se, is concerned, four principal factors need be discussed in order that the provisions of the Specification may be 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 hot-dip galvanized coatings on the nut stripping strength, (3) the effect of galvanizing upon the torque involved in the tightening operation, and (4) shipping requirements.

The ASTM Specifications for galvanized A325 high-strength bolts recognize

Table C2

Nominal Bolt Size, Inches	To Determine Required Bolt Length Add to Grip, in Inches
1/2	11/16
5/8	7/8
3/4	1
7/8	1 1/8
1	1 1/4
1 1/8	1 1/2
1 1/4	1 5/8
1 3/8	1 3/4
1 1/2	1 7/8

both the hot-dip galvanizing process and the mechanical galvanizing process. 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 which follow. ASTM A325 Specifications require that all components of a fastener assembly (nuts, bolts and washers) shall have been coated by the same process and that the supplier's option is limited to one process per item with no mixed processes in a lot. Mixing a bolt galvanized by one process with a nut galvanized by the other may result in a unworkable assembly.

Effect of Hot-Dip Galvanizing on the Strength of Steels. 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 A325 bolts is 105 or 120 ksi, depending upon the size, comfortably below the critical range. The required maximum tensile strength for A490 bolts was set at 170 ksi in order to provide a little more than a 10 percent margin below 200 ksi; however, because manufacturers must target their production slightly higher than the required minimum, A490 bolts close to the critical range of tensile strength must be anticipated. For black bolts this is not a cause for concern, but, if the bolt is hot-dip galvanized, a hazard of delayed brittle fracture in service exists because of the real possibility of introduction of hydrogen into the steel 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 adsorption arising from corrosion process in service in aggressive environments. ASTM Specifications provide for the galvanizing of A325 bolts but not A490 bolts. Galvanizing of A490 bolts is not permitted. Because pickling and emersion in molten zinc is not involved, galvanizing by the mechanical process essentially avoids potential for hydrogen embrittlement.

The heat treatment temperatures for Type 2 ASTM A325 bolts are in the range of the molten zinc temperatures for hot-dip galvanizing; therefore there is a potential for diminishing the heat treated mechanical properties of Type 2 A325 bolts by the hot-dip galvanizing process. For this reason, the current Specifications require that only mechanical galvanizing shall be used on Type 2 ASTM A325 bolts.

Nut Stripping Strength. Hot-dip galvanizing affects the stripping strength of the nut-bolt assembly primarily 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 oversize after galvanizing. This overtapping results in a reduction in the amount of engagement between the steel portions of the male and female threads with a consequent approximately 25 percent reduction in the stripping strength. Only the stronger hardened nuts have adequate strength to meet specification requirements even with the reduction due to overtapping; therefore, ASTM A325 specifies that only Grades DH and 2H be used for 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 oversize before galvanizing by an amount less than required for the hot-dip process before galvanizing. This results in a better bolt-nut fit with zinc coating on the internal threads of the nut.

Effect of Galvanizing Upon Torque Involved in Tightening. Research[3] has shown that, in the as-galvanized condition, galvanizing both increases the friction between the bolt and nut threads and also makes the torque induced tension much more variable. Lower torque and more consistent results are provided if the nuts are lubricated; thus, ASTM A325 requires that a galvanized bolt and lubricated galvanized nut shall be assembled in a steel joint with a galvanized washer and tested in accordance with ASTM A563 by the manufacturer prior to shipment to ensure that the galvanized nut with the lubricant provided may be rotated from the snug tight condition well in excess of the rotation required for full tensioning of the bolts without stripping. The requirement applies to both hot-dip and mechanical galvanized fasteners.

Shipping Requirements for Galvanized Bolts and Nuts. The above requirements clearly indicate (1) that galvanized bolts and nuts are to be treated as a matched assembly, (2) that the seller must supply nuts which have been lubricated and tested with the supplied bolts, and (3) that nuts and bolts must be shipped together in the same shipping container. Purchase of galvanized bolts and galvanized nuts from separate sources is not in accordance with the intent of the ASTM Specifications because the control of overtapping and the testing and application of lubricant would be lost. Because some of the lubricants used to meet the requirements of ASTM Specifications are water soluble, it is advisable that galvanized bolts and nuts be shipped and stored in plastic bags in wood or metal containers.

Washers. The primary function of washers is to provide a hardened non-galling surface under the element turned in tightening, particularly for those installation procedures which depend upon torque for control or inspection. Circular hardened washers meeting the requirements of ASTM A436 provide an increase in bearing area of 45 to 55 percent over the area provided by a heavy hex bolt head or nut; however, tests have shown that standard thickness washers play only a minor role in distributing the pressure induced by the bolt pretension, except where oversize or short slotted holes are used. Hence, consideration is given to this function only in the case of oversize and short slotted holes. The requirement for standard thickness hardened washers, when such washers are specified as an aid in the distribu-

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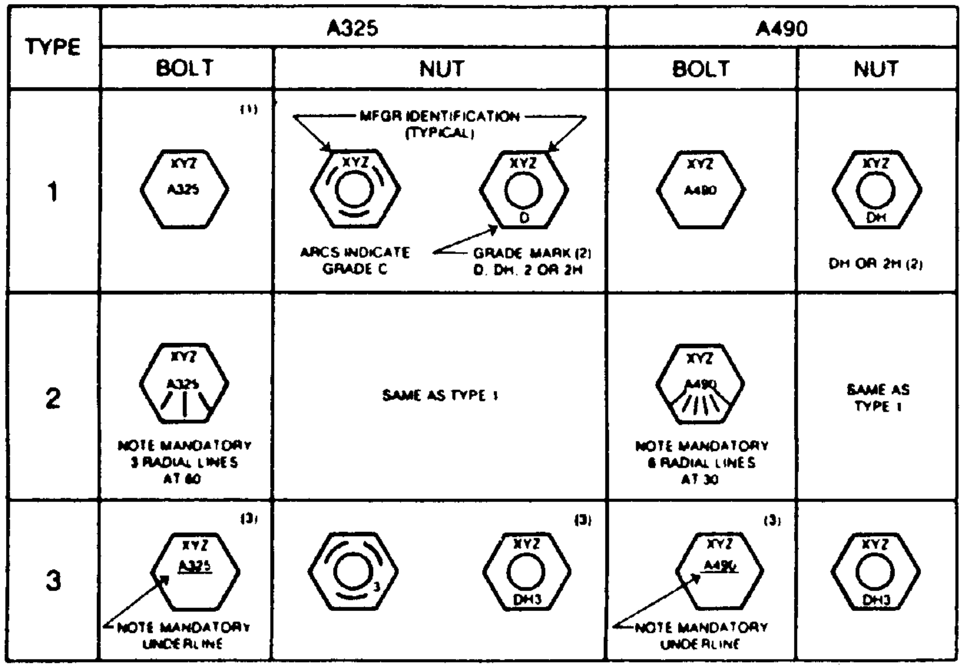
3. Birkemoe, P. C., and D. C. Herrschaft, "Bolted Galvanized Bridges—Engineering Acceptance Near," ASCE *Civil Engineering,* April 1970.



(1) ADDITIONAL OPTIONAL 3 RADIAL LINES AT 120° MAY BE ADDED
(2) TYPE 3 ALSO ACCEPTABLE
(3) ADDITIONAL OPTIONAL MARK INDICATING WEATHERING GRADE MAY BE ADDED

Fig. C2. Required marking for acceptable bolt and nut assemblies

tion of pressure, is waived for alternative design fasteners which incorporate a bearing surface under the head of the same diameter as the hardened washer; however, the requirements for hardened washers to satisfy the principal requirement of providing a non-galling surface under the element turned in tightening is not waived. The maximum thickness is the same for all standard washers up to and including 1½ inch bolt diameter in order that washers may be produced from a single stock of material.

The requirement that heat-treated washers not less than $\frac{5}{16}$ inch thick be used to cover oversize and slotted holes in external plies, when A490 bolts of $1\frac{1}{8}$ inch or larger diameter are used, was found necessary to distribute the high clamping pressure so as to prevent collapse of the hole perimeter and enable development of the desired clamping force. Preliminary investigation has shown that a similar but less severe deformation occurs when oversize or slotted holes are in the interior plies. The reduction in clamping force may be offset by "keying," which tends to increase the resistance to slip. These effects are accentuated in joints of thin plies.

Marking. Heavy hex structural bolts and 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 marking. The mandatory and optional markings are shown in Figure C2.

Paint. In the previous edition of the Specification, generic names for paints applied to faying surfaces was the basis for categories of allowable working stresses in "friction" type connections. Research[4] completed since the adoption of the 1980 Specification has demonstrated that the slip coefficients for paints described by a generic type are not single values but depend also upon the type of vehicle used. Small differences in formulation from manufacturer to manufacturer or from lot to lot with a single manufacturer significantly affect slip coefficients if certain essential variables within a generic type are changed. It is unrealistic to assign paints to categories with relatively small incremental differences between categories based solely upon a generic description. As a result of the research, a test method was developed and adopted by the Council titled "Test Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints." A copy of this document is appended to this Specification as Appendix A. The method, which requires requalification if an essential variable is changed, is the sole basis for qualification of any coating to be used under this Specification. Further, normally only two categories of slip coefficient for paints to be used in slip-critical joints are recognized: Class A for coatings which do not reduce the slip coefficient below that provided by clean mill scale, and Class B for paints which do not reduce the slip coefficient below that of blast-cleaned steel surfaces.

The research cited in the preceding paragraph also investigated the effect of varying the time from coating the faying surfaces to assembly of the connection and tightening the bolts. The purpose was to ascertain if partially cured paint continued to cure within the assembled joint over a period of time. It was learned that all curing ceased at the time the joint was assembled and tightened and that paint coatings that were not fully cured acted much as a lubricant would; thus, the slip resistance of the joint was severely reduced from that which was provided by faying surfaces that were fully cured prior to assembly.

C3 Bolted Parts

Material Within the Grip. The Specification is intended to apply to structural joints in which all of the material within the grip of the bolt is steel.

Surface Conditions. The Test Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints includes long-term creep test requirements to ensure reliable performance for qualified paint coatings. However, it must be recognized that in the case of hot-dip galvanized coatings, especially if the joint consists of many plies of thickly coated material, relaxation of bolt tension may be significant and may require retensioning of the bolts subsequent to the initial tightening. Research[5] has shown that a loss of pretension of approximately 6.5 percent occurred for galvanized plates and bolts due to relaxation as compared with 2.5 percent for uncoated joints. This loss of bolt tension occurred in five days with negligible loss recorded thereafter. This loss can be allowed for in design or pretension may be brought back to the prescribed level by retightening the bolts after an initial period of "settling-in."

Since it was first published, this Specification has permitted the use of bolt holes $\frac{1}{16}$ inch larger than the bolts installed in them. Research[6] has shown that, where

4. Frank, Karl H. and J. A. Yura, "An Experimental Study of Bolted Shear Connections." FHWA/RD-81/148, December 1981.

5. Munse, W. H., "Structural Behavior of Hot Galvanized Bolted Connections," 8th International Conference on Hot-dip Galvanizing, London, England, June 1967.

6. Allen, R. N. and J. W. Fisher, "Bolted Joints With Oversize or Slotted Holes," ASCE *Journal of the Structural Division*, Vol. 94, No. ST9, September, 1968.

greater latitude is needed in meeting dimensional tolerances during erection, somewhat larger holes can be permitted for bolts ⅝ inch diameter and larger without adversely affecting the performance of shear connections assembled with high-strength bolts. The oversize and slotted hole provisions of this Specification are based upon these findings. Because an increase in hole size generally reduces the net area of a connected part, the use of oversize holes is subject to approval by the Engineer of Record.

Burrs. Based upon tests[7] which demonstrated that the slip resistance of joints was unchanged or slightly improved by the presence of burrs, burrs which do not prevent solid seating of the connected parts in the snug tight condition need not be removed. On the other hand, parallel tests in the same program demonstrated that large burrs can cause a small increase in the required turns from snug tight condition to achieve specified pretension with turn-of-nut method of tightening.

Unqualified Paint on Faying Surfaces. An extension to the research on the slip resistance of shear connections cited in footnote 4 investigated the effect of ordinary paint coatings on limited portions of the contact area within joints and the effect of overspray over the total contact area. The tests[8] demonstrated that the effective area for transfer of shear by friction between contact surfaces was concentrated in an annular ring around and close to the bolts. Paint on the contact surfaces approximately one inch but not less than the bolt diameter away from the edge of the hole did not reduce the slip resistance. On the other hand, in recognition of the fact that, in connections of thick material involving a number of bolts on multiple gage lines, bolt pretension might not be adequate to completely flatten and pull thick material into tight contact around every bolt, the Specification requires that all areas between bolts also be free of paint. (See Figure C3.) The new requirements have a potential for increased economy because the paint-free area may easily be protected using masking tape located relative to the hole pattern, and, further, the narrow paint strip around the perimeter of the faying surface will minimize uncoated material outside the connection requiring field touch-up.

This research also investigated the effect of various degrees of inadvertent overspray on slip resistance. It was found that even the smallest amount of overspray of ordinary paint (that is, not qualified as Class A) within the specified paint-free area on clean mill scale reduced the slip resistance significantly. On blast-cleaned surfaces, the presence of a small amount of overspray was not as detrimental. For simplicity, the Specification prohibits any overspray from areas required to be free of paint in slip-critical joints regardless of whether the surface is clean mill scale or blast cleaned.

Galvanized Faying Surfaces. The slip factor for initial slip with clean hot-dip galvanized surfaces is of the order of 0.19 as compared with a factor of about 0.35 for clean mill scale. However, research (see note 3) has shown that the slip factor of galvanized surfaces is significantly improved by treatments such as hand wire brushing or light "brush-off" grit blasting. In either case, the treatment must be controlled in order to achieve the necessary roughening or scoring. Power wire brushing is unsatisfactory because it tends to polish rather than roughen the surface.

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7. Polyzois, D. and J. A. Yura, "Effect of Burrs on Bolted Friction Connections," AISC *Engineering Journal*, 22 (No. 3) Third Quarter 1985.

8. Polyzois, D. and K. Frank, "Effect of Overspray and Incomplete Masking of Faying Surfaces on the Slip Resistance of Bolted Connections," AISC *Engineering Journal*, 23 (No. 2), 2nd Quarter 1986.

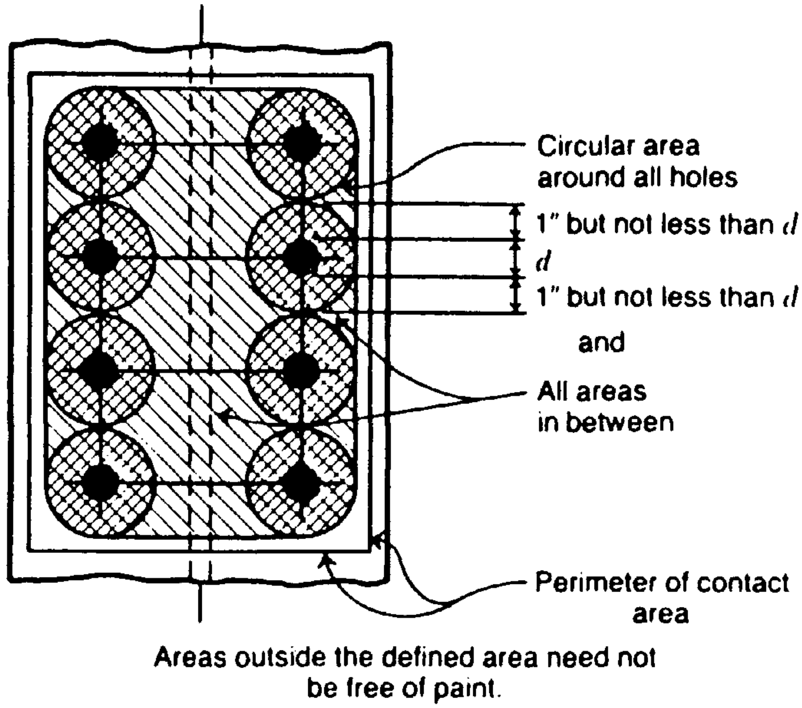

Fig. C3. Areas outside the defined area need not be free of paint

Field experience and test results have indicated that galvanized members may have a tendency to continue to slip under sustained loading.[9] Tests of hot-dip galvanized joints subject to sustained loading show a creep-type behavior. Treatments to the galvanized faying surfaces prior to assembly of the joint which caused an increase in the slip resistance under short duration loads did not significantly improve the slip behavior under sustained loading.

C4 Design for Strength of Bolted Connections

Background for Design Stresses. With the 1985 edition of the Specification, the arbitrary designations "friction type" and "bearing type" connections used in former editions, and which were frequently misinterpreted as implying an actual difference in the manner of performance or strength of the two types of connection, were discontinued in order to focus attention more upon the real manner of performance of bolted connections.

In bolted connections subject to shear-type loading, the load is transferred between the connected parts by friction up to a certain level of force which is dependent upon the total clamping force on the faying surfaces and the coefficient of friction of the faying surfaces. The connectors are not subject to shear, nor is the connected material subject to bearing stress. As loading is increased to a level in excess of the frictional resistance between the faying surfaces, slip occurs, but failure in the sense of rupture does not occur. As even higher levels of load are applied, the load is resisted by shear in the fastener and bearing upon the connected material plus some uncertain amount of friction between the faying surfaces. The final failure will be by shear failure of the connectors, or by tear out of the connected

9. Kulak, G. L., J. W. Fisher, and J. H. A. Struik, "Guide to Design Criteria for Bolted and Riveted Joints," 2nd ed., New York: John Wiley & Sons, 1987, p. 208. (Hereinafter referred to as the *Guide*.)

material, or by unacceptable ovalization of the holes. Final failure load is independent of the clamping force provided by the bolts.[10]

The design of high-strength bolted connections under this Specification begins with consideration of strength required to prevent premature failure by shear of the connectors or bearing failure of the connected material. Next, for connections which are defined as "slip-critical," the resistance to slip load is checked. Because the combined effect of frictional resistance with shear or bearing has not been systematically studied and is uncertain, any potential greater resistance due to combined effect is ignored.

Connection Slip. There are practical cases in the design of structures where slip of the connection is desirable in order to permit rotation in a joint or to minimize the transfer of moment. Additionally there are cases where, because of the number of fasteners in a joint, the probability of slip is extremely small or where, if slip did occur, it would not be detrimental to the serviceability of the structure. In order to provide for such cases while at the same time making use of the higher shear strength of high-strength bolts, as contrasted to ASTM A307 bolts, the Specification now permits joints tightened only to the snug tight condition.

The maximum amount of slip that can occur in connections that are not classified as slip-critical is, theoretically, an amount equal to two hole clearances. In practical terms, it is observed to be much less than this. In laboratory tests it is usually about one-half a hole clearance. This is because the acceptable inaccuracies in the location of holes within a pattern of bolts would usually cause one or more bolts to be in bearing in the initial unloaded condition. Further, in statically loaded structures, even with perfectly positioned holes, the usual method of erection would cause the weight of the connected elements to put the bolts into direct bearing at the time the member is supported on loose bolts and the lifting crane is unhooked. Subsequent additional gravity loading could not cause additional connection slip.

Connections classified as slip-critical include those cases where slip could theoretically exceed an amount deemed by the Engineer of Record to affect the suitability for service of the structure by excessive distortion or reduction in strength or stability, even though the resistance to fracture of the connection, per se, may be adequate. Also included are those cases where slip of any magnitude must be prevented, for example, joints subject to load reversal.

Shear and Bearing on Fasteners. Several interrelated parameters influence the shear and bearing strength of connections. These include such geometric parameters as the net-to-gross-area ratio of the connected parts, the ratio of the net area of the connected parts to the total shear-resisting area of the fasteners, and the ratio of transverse fastener spacing to fastener diameter and to the connected part thickness. In addition, the ratio of yield strength to tensile strength of the steel comprising the connected parts, as well as the total distance between extreme fasteners, measured parallel to the line of direct tensile force, play a part.

In the past, a balanced design concept had been sought in developing criteria for mechanically fastened joints to resist shear between connected parts by means of bearing of the fasteners against the sides of the holes. This philosophy resulted in wide variations in the factor of safety for the fasteners, because the ratio of yield to tensile strength increases significantly with increasingly stronger grades of steel. It had no application at all in the case of very long joints used to transfer direct

10. Ibid., pp. 49–52.

tension, because the end fasteners "unbutton" before the plate can attain its full strength or before the interior fasteners can be loaded to their rated shear capacity.

By means of a mathematical model it was possible to study the interrelationship of the previously mentioned parameters.[11,12] It has been shown that the factor of safety against shear failure ranged from 3.3 for compact (short) joints to approximately 2.0 for joints with an overall length in excess of 50 inches. It is of interest to note that the longest (and often the most important) joints had the lowest factor, indicating that a factor of safety of 2.0 has proven satisfactory in service.

The absence of design strength provisions specifically for the case where a bolt in double shear has a non-threaded shank in one shear plane and a threaded section in the other shear plane is because of the uncertainty of manner of sharing the load between the two different shear areas. It also recognizes that knowledge as to the bolt placement (which might leave both shear planes in the threaded section) is not ordinarily available to the detailer. If threads occur in one shear plane, the conservative assumption is made that threads are in all shear planes.

The nominal strength and resistance factors for fasteners subject to applied tension or shear are given in Table 2. The values are based upon the research and recommendations reported in the *Guide*. With the wealth of data available, it was possible through statistical analyses to adjust resistances to provide more uniform reliability for all loading and joint types. The design resistances provide designs approximately equivalent to the designs provided by the allowable stresses in the 1980 edition of the Specification. The design of connections is more conservative than that of the connected members of buildings and bridges by a substantial margin, in the sense that the failure load of the fasteners is substantially in excess of the maximum serviceability limit (yield) of the connected material.

Design for Tension. The nominal strengths specified for applied tension[13] are intended to apply to the external bolt load plus any tension resulting from prying action produced by deformation of the connected parts. The recommended design strength is approximately equal to the initial tightening force; thus, when loaded to the nominal (service) load, high-strength bolts will experience little if any actual change in stress. For this reason, bolts in connections in which the applied loads subject the bolts to axial tension are required to be fully tensioned, even though the connection may not be subject to fatigue loading nor classified as slip-critical.

Properly tightened A325 and A490 bolts are not adversely affected by repeated application of the recommended service load tensile stress, provided the fitting material is sufficiently stiff, so that the prying force is a relatively small part of the applied tension.[14] The provisions covering bolt tensile fatigue are based upon study of test reports of bolts that were subjected to repeated tensile load to failure.

Design for Shear. The nominal strength in shear is based upon the observation that the shear strength of a single high-strength bolt is about 0.62 times the tensile strength of that bolt.[15] However, in shear connections with more than two bolts in the line of force, deformation of the connected material causes nonuniform bolt shear force distribution so that the strength of the connection in terms of the average bolt strength

11. Fisher, J. W. and L. S. Beedle, "Analysis of Bolted Butt Joints," ASCE *Journal of the Structural Division*, 91 (No. ST5), October 1965.
12. *Guide*, pp. 89–116; 126–132.
13. Ibid., pp. 263–286.
14. Ibid., pp. 272.
15. Ibid., pp. 44–50.

goes down as the joint length increases.[16] Rather than provide a function that reflects this decrease in average fastener strength with joint length, a single reduction factor of 0.80 was applied to the 0.62 multiplier. The result will accommodate bolts in all joints up to about 50 inches in length without seriously affecting the economy of very short joints. As noted in the footnotes to Table 2, bolts in joints longer than 50 inches in length must be further discounted by an additional 20 percent.

The average value of the nominal strength for bolts with threads in the shear plane has been determined by a series of tests[17] to be 0.833 F_u with a standard deviation of 0.03. A value of 0.80 was taken as a factor to account for the shear strength of a bolt with threads in the shear plane based upon the area corresponding to the nominal body area of the bolt.

The shear strength of bolts is not affected by pretension in the fasteners provided the connected material is in contact at the faying surfaces.

The design shear strength equals the nominal shear strength multiplied by a resistance factor of 0.75.

Combined Tension and Shear. The nominal strength of fasteners subject to combined tension and shear is provided by elliptical interaction curves in Table 3 which account for the connection length effect on bolts loaded in shear, the ratio of shear strength to tension strength of threaded fasteners, and the ratios of root area to nominal body area and tensile stress area to nominal body area.[18] No reduction in the design shear strength is required when applied tensile stress is equal to or less than the design tensile strength. Although the elliptical interaction curve provides the best estimate of the strength of bolts subject to combined shear and tension and thus is used in this Specification, it would be within the intent of the Specification for invoking specifications to use a three straight line approximation of the ellipse.

Design for Bearing. Bearing stress produced by a high-strength bolt pressing against the side of the hole in a connected part is important only as an index to behavior of the connected part. It is of no significance to the bolt. The critical value can be derived from the case of a single bolt at the end of a tension member.

It has been shown,[19] using finger-tight bolts, that a connected plate will not fail by tearing through the free edge of the material if the distance L, measured parallel to the line of applied force from a single bolt to the free edge of the member toward which the force is directed, is not less than the diameter of the bolt multiplied by the ratio of the bearing stress to the tensile strength of the connected part.

The criterion for nominal bearing strength is

$$L/d \geq R_n/F_u$$

where

R_n = nominal bearing pressure

F_u = specified minimum tensile strength of the connected part.

As a practical consideration, a lower limit of 1.5 is placed on the ratio L/d and an upper limit of 1.5 on the ratio F_p/F_u and an upper limit of 3.0 on the ratio R_n/F_u.

The foregoing leads to the rules governing bearing strength in the specification.

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16. Ibid., pp. 99–104.
17. Yura, J. A., K. H. Frank, and D. Polyois, "High Strength Bolts for Bridges." *PMFSEL Report No. 87-3*, May 1987, Phil M. Ferguson Structural Engineering Laboratory, University of Texas at Austin.
18. *Guide*, pp. 50–51.
19. Ibid., pp. 141–143.

The bearing pressure permitted in the 1980 Specification and the current provisions are fully justifiable from the standpoint of strength of the connected material. However, even though rupture does not occur, recent tests have demonstrated that ovalization of the hole will begin to develop as the bearing stress is increased beyond the previously permitted stress, especially if it is combined with high tensile stress on the net section. Furthermore, when high bearing stress is combined with high tensile stress on the net section and the effect of exterior versus interior plies, lower ultimate strengths than previously reported result in addition to the hole ovalization.

Recognizing that initiation of hole ovalization occurs well below the ultimate strength, and to facilitate standardization in detailing and fabrication, sufficiently conservative simplified criteria have been provided in a formula format for usual applications. The more accurate formula in which the strength is related to the distance L may be used for special cases such as those with very large bolts or very thin material.

For connections with more than a single bolt in the direction of force, the resistance may be taken as the sum of the resistances of the individual bolts.

C5 Design Check for Slip Resistance

The Specification recognizes that, for a number of cases, slip of a joint would be undesirable or must be precluded. Such joints are termed "slip-critical" joints. This is somewhat different from the previous term "friction type" connection. The new terminology was adopted in order to focus attention on the fact that all tightened high-strength bolted joints resist load by friction between the faying surfaces up to the slip load and subsequently are able to resist even greater loads by shear and bearing. The strength of the joint is not related to the slip load. The Specification requires that the two different resistances be considered separately.

The consequences of slip into bearing varies from application to application; hence the determination of which connections shall be designed and installed as slip-critical is best left to judgment and a conscious decision on the part of the Engineer of Record. Also, the determination of whether the potential slippage of a joint is critical at nominal load level as a serviceability consideration or whether slippage could result in distortions of the frame such that the ability of the frame to resist factored loads would be reduced can be determined only by the Engineer of Record. The following comments reflect the collective thinking of the Council as developed during numerous meetings and reviews of drafts of the Specification and Commentary. They are provided as guidance and an indication of the intent of the Specification.

In the case of bolts in holes with only small clearance, such as standard holes and slotted holes loaded transverse to the axis of the slot in practical connections, the freedom to slip generally does not exist because one or more bolts are in bearing even before load is applied due to normal fabrication tolerances and erection procedures. Further, the consequences of slip, if it can occur at all, are trivial except for a few situations. If for some reason it is deemed critical, design should probably be on the basis of nominal loads (Section 5(b)).

In connections containing long slots that are parallel to the direction of the applied load, slip of the connection prior to attainment of the factored load might be large enough to alter the usual assumption of analysis that the undeformed structure can be used to obtain the internal forces. The Specification allows the designer two alternatives in this case. If the connection is designed so that it will not slip under the effect of the nominal loads, then the effect of the factored loads acting on the deformed structure (deformed by the maximum amount of slip in the long slots at all locations) must be included in the structural analysis. Alternatively the connection can be designed so that it will not slip at loads up to the factored load level. These requirements are noted in Clause 7(b)(3).

Joints subject to full reverse cyclic loading are clearly slip-critical joints since slip would permit back-and-forth movement of the joint and early fatigue failure. However, for joints subject to pulsating load that does not involve reversal of load direction, proper fatigue design could be provided either as a slip-critical joint on the basis of stress on the gross section or as a non-slip-critical joint on the basis of stress on the net section. Because fatigue results from repeated application, the service load rather than the overload load design should be based upon nominal load criteria (Section 5(b)).

For high-strength bolts in combination with welds in statically loaded conditions and considering new work only, the nominal strength may be taken as the sum of two contributions.[20] One results from the slip resistance of the bolted parts and may be determined in accordance with Section 5(c). The second results from the resistance of the welds as provided by applicable welding specifications. If one type of connector is already loaded when the second type of connector is introduced, the nominal strength cannot be obtained by adding the two resistances. The *Guide* should be consulted in these cases.

From the definition of the term "coefficient of slip" (friction), the expression for nominal slip resistances for bolts in standard holes is apparent and needs no explanation. The mean value of slip coefficients from many tests on clean mill scale, blast-cleaned steel surfaces and galvanized and roughened surfaces were taken as the basis for the three classes of surfaces.

In the 1978 edition of the Specification, nine classes of faying surface conditions were introduced, and significant increases were made in the recommended allowable stresses for proportioning connections which function by transfer of shear between connected parts by friction. These classes and stresses were adopted on the basis of statistical evaluation of the information then available.

Extensive data developed through research sponsored by the Council and others during the past ten years has been statistically analyzed to provide improved information on slip probability of connections in which the bolts have been preloaded to the requirements of Table 4. Two principal variables—coefficient of friction of the faying surfaces and bolt pretension—were found to dominate the slip resistance of connections.

An examination of the slip (friction) coefficient data for a wide range of surface conditions indicates that the data are distributed normally, and the standard deviation is essentially the same for each surface condition class. This means that different reduction factors should be applied to classes of surfaces with different mean values of coefficients of friction—the smaller the mean value of the coefficient of friction, the smaller (more severe) the appropriate reduction factor—in order to provide equivalent reliability of slip resistance.

The bolt clamping force data indicate that bolt tensions are distributed normally for each method of tightening. However, the data also indicate that the mean values of the bolt tensions are different for each method. If the calibrated wrench method is used to tighten ASTM A325 bolts, the mean value of bolt tension is about 1.13

20. Ibid., pp. 238–40.

times the minimum specified tension in Table 4. If the turn-of-nut method is used, the mean value of tension is about 1.35 times the minimum specified preload for A325 bolts and about 1.27 for A490 bolts.

The combined effects of the variability of coefficient of friction and bolt tension have been accounted for in the slip probability factor, *D*, of the formula for nominal slip resistance in Section 5(b). The values of the slip probability factor, *D*, given by 5(b) imply a 90 percent reliability that slip will not occur if the calibrated wrench method of installation is used. If the turn-of-nut method is used, a reliability of about 95 percent will be provided.

Reference is made to *Guide to Design Criteria for Bolted and Riveted Joints* (2nd ed., New York: John Wiley and Sons, 1987 p. 135) for tables of values of *D* appropriate for other mean slip coefficients and slip probabilities and suitable for direct substitution into the formula for slip resistance in Section 5(b).

The frequency distribution and mean value of clamping force for bolts tightened by turn-of-nut method are higher than calibrated wrench installation because of the elimination of variables which affect torque-tension ratios and due to higher-than-specified minimum strength of production bolts. Because properly applied turn-of-nut installation induces yield point strain in the bolt, the higher-than-specified yield strength of production bolts will be mobilized and result in higher clamping force by the method. On the other hand, the calibrated wrench method, which is dependent upon the calibration of wrenches to slightly more than Table 4 tensions, independent of the actual bolt properties, will not mobilize any additional strength of production bolts. High clamping force might be achieved by the calibrated wrench method if the wrench was set to a higher torque value. However, this would require more attention to the degrees of rotation to prevent excessive deformation of the bolt or torsional bolt failure.

Because of the effects of oversize and slotted holes on the induced tension in bolts using any of the specified installation methods, lower values are provided for bolts in these hole types. In the case of bolts in long slotted holes, even though the slip load is the same for bolts loaded transverse or parallel to the axis of the slot, the values for bolts loaded parallel to the axis has been further reduced based upon judgment in recognition of the greater consequences of slip.

Attention is called to the fact that the criteria for slip resistance are for the case of connections subject to a coaxial load. For cases in which the load tends to rotate the connection in the plane of the faying surface, a modified formula accounting for the placement of bolts relative to the center of rotation should be used.[21]

Connections of the type shown in Figure C4(a), in which some of the bolts (A) lose a part of their clamping force due to applied tension, suffer no overall loss of frictional resistance. The bolt tension produced by the moment is coupled with a compensating compressive force (*C*) on the other side of the axis of bending. In a connection of the type shown in Fig. C4(b), however, all fasteners (B) receive applied tension which reduces the initial compression force at the contact surface. If slip under load cannot be tolerated, the design slip-load value of the bolts in shear should be reduced in proportion to the ratio of residual axial force to initial tension. If slip of the joint can be tolerated, the bolt shear stress should be reduced according to the tension-shear interaction as outlined in the *Guide*, page 71. Because the bolts are subject to applied axial tension, they are required to be pretensioned in either case.

21. Ibid., pp. 217–30.

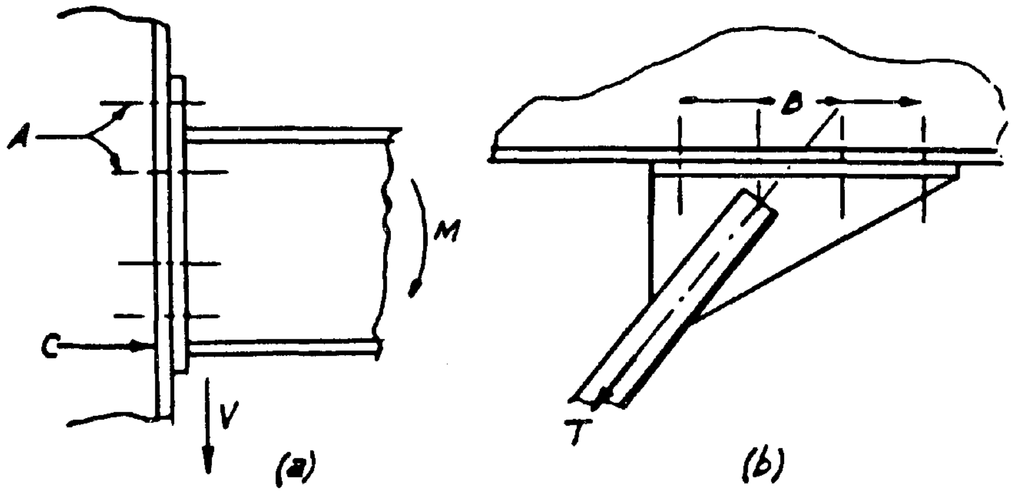

Fig. C4

While connections with bolts pretensioned to the levels specified in Table 4 do not ordinarily slip into bearing when subject to anticipated loads, it is required that they meet the requirements of Section 5 in order to maintain the factor of safety of 2 against fracture in the event that the bolts do slip into bearing as a result of large unforeseen loads.

To cover those cases where a coefficient of friction less than 0.33 might be adequate for a given situation, the Specification provides that, subject to the approval of the Engineer of Record, and provided the mean slip coefficient is determined by the specified test procedure and the appropriate slip probability factor, *D*, is selected from the literature, faying surface coatings providing lower slip resistance than Class A coating may be used.

It should be noted that both Class A and Class B coatings are required to be applied to blast-cleaned steel.

High-Strength Bolts in Combination with Welds or Rivets. For high-strength bolts in combination with welds in statically loaded conditions and considering new work only, the nominal strength may be taken as the sum of the two contributions. If one type of connector is already loaded when the second type of connector is introduced, the nominal strength cannot be obtained by sum of the two resistances. The *Guide* should be consulted in these cases.

For high-strength bolts in combination with welds in fatigue loaded applications, available data are not sufficient to develop general design recommendations at this time. High-strength bolts in combination with rivets are rarely encountered in modern practice. If need arises, guidance may be found in the *Guide.*

C7 Design Details of Bolted Connections

A new section has been added with this edition of the Specification in order to bring together a number of requirements for proper design and detailing of high-strength bolted connections. The material covered in the Specification, and in Section 7 in particular, is not intended to provide comprehensive coverage of the design of high-strength bolted connections. For example, other design considerations of importance to the satisfactory performance of the connected material such as block shear, shear lag, prying action, connection stiffness, effect on the performance of the structure and others are beyond the scope of this Specification and Commentary.

Proper location of hardened washers is as important as other elements of a detail to the performance of the fasteners. Drawings and details should clearly reflect the number and disposition of washers, especially the thick hardened washers that are required for several slotted hole applications. Location of washers is a design consideration that should not be left to the experience of the iron worker.

While hardened washers are not required with some methods of installation, their use will overcome the effects of galling under the element turned in tightening.

Finger shims are a necessary device or tool of the trade to permit adjusting alignment and plumbing of structures. When these devices are fully and properly inserted, they do not have the same effect on bolt tension relaxation or the connection performance as do long slotted holes in an outer ply. When fully inserted, the shim provides support around approximately 75 percent of the perimeter of the bolt in contrast to the greatly reduced area that exists with a bolt centered in a long slot. Further, finger shims would always be enclosed on both sides by the connected material which would be fully effective in bridging the space between the fingers.

C8 Installation and Tightening

Several methods for installation and tensioning of high-strength bolts, when tensioning is required, are provided without preference in the Specification. Each method recognized in Section 8, when properly used as specified, may be relied upon to provide satisfactory results. All methods may be misused or abused.

At the expense of redundancy, the provisions stipulating the manner in which each method is intended to be used are set forth in complete detail in order that the rules for each method may stand alone without need for footnotes or reference to other sections. If the methods are conscientiously implemented, good results should be routinely achieved.

Connections Not Requiring Full Tensioning. In the Commentary, Section C6 of the previous edition of the Specification, it was pointed out that "bearing" type connections need not be tested to ensure that the specified pretension in the bolts had been provided, but specific provision permitting relaxation of the tensioning requirement was not contained in the body of the Specification. In the present edition of the Specification, separate installation procedures are provided for bolts that are not within the slip-critical or direct tension category. The intent in making this change is to improve the quality of bolted steel construction and reduce the frequency of costly controversies by focusing attention, both during the installation and tensioning phase and during inspection, on the true slip-critical connections, rather than diluting the effort through the requirement for costly tensioning and tension testing of the great many connections where such effort serves no useful purpose. The requirement for identification of connections on the drawings may be satisfied either by identifying the slip-critical and direct tension connections which must be fully tightened and inspected or by identifying the connections which need be tightened only to the snug tight condition.

Under the provisions of some other specifications, certain shear/bearing connections are required to be tightened well beyond the snug tight conditions;[22] how-

22. For example, American Institute of Steel Construction, "Specification for Design Fabrication and

ever, because the joints are in bearing, prevention of slip of the joint is not a concern in these connections. Because they are not slip-critical joints, they should not be subject to the same requirements as slip-critical joints, especially the requirements for faying surface coatings and conditions. To ensure proper tightness of the connections, they should be tightened by one of the four methods in 8(d); however, inspection should be limited to monitoring the work to confirm that the bolt tightening procedure is properly applied. Inspection should not include testing to ensure that any specific level of tension has been achieved.

In the Specification, snug tight is defined as the tightness that exists when all plies are in firm contact. This may usually be attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. In actuality, snug tight is a degree of tightness which will vary from joint to joint depending upon the thickness, flatness and degree of parallelism of the connected material. In most joints, the plies will pull together at snug tight; however, in some joints in thick material, it may not be possible to have continuous contact throughout the faying surface area. In such joints, the slip resistance of the completed joints will not be reduced because compressive forces between the faying surfaces, however distributed, must be in equilibrium with the total of the tensile forces in all bolts.

Tension Calibrating Devices. At the present time, there is no known economical means for determining the tension in a bolt that has previously been installed in a connection. The actual tension in a bolt installed in a tension calibrator (hydraulic tension indicating device) is directly indicated by the dial of the device, provided the device is properly calibrated. Such a device is an economical and valuable tool that should be readily available whenever high-strength bolts are to be installed in either slip-critical or shear/bearing connections. The testing of as-recieved bolts and nuts at the job site is a requirement of the Specification because instances of counterfeit under strength fasteners not meeting the requirements of the ASTM Specification have not infrequently occurred. Job site testing provides a practical means for ensuring that nonconforming fasteners are not incorporated in the work. Further, although the several elements of a fastener assembly may conform to the minimum requirements of their separate ASTM Specifications, their compatibility in an assembly or the need for lubrication can only be ensured by testing of the assembly. Hence, such devices are important for testing the complete fastener assembly as it will be used with the method of tightening to be used to ensure the suitability of bolts and nuts (probably produced by different manufacturers), other elements, and the adequacy of impact wrenches and/or air pressure to provide the specified tension using the selected method. Testing before start of installation of fasteners in the work will also identify potential sources of problems, such as the need for lubrication to prevent failure of bolts by combined high torque with tension, under-strength assemblies due to excessive overtapping of hot-dip galvanized nuts, and to clarify for the bolting crews and inspectors the proper implementation of the selected installation method to be used. Such devices are essential to the confirmation testing of alternative design fasteners, direct tension indicators, and to verify the proper use of the turn-of-nut procedure. They are also essential to the specified procedure for the calibrated wrench method of installation, and for the specified procedure for determining a valid testing torque when such inspection by a torque method is required.

Erection of Structural Steel for Buildings," Section 1.15.12, stipulates several cases where high-strength bolts in bearing connections are to be fully tensioned independent of whether potential slip is a concern or not.

They are the only known economically available tool for field use for determining realistic torque to tension relationships for given fastener assemblies.

Experience on many projects has shown that bolts and/or nuts not meeting the requirements of the applicable ASTM specification would have been identified prior to installation if they had been tested as an assembly in a tension calibrator. The controversy and great expense of replacing bolts installed in the structure when the nonconforming bolts were discovered at a later date would have been avoided.

Hydraulic tension calibrating devices capable of indicating bolt tension undergo a slight deformation under load. Hence, the nut rotation corresponding to a given tension reading may be somewhat larger than it would be if the same bolt were tightened against a solid steel abutment. Stated differently, the reading of the calibrating device tends to underestimate the tension which a given rotation of the turned element would induce in a bolt in an actual joint. This should be borne in mind when using such devices to establish a tension-rotation relationship.

Slip-critical Connections and Connections Subject to Direct Tension. Four methods for joint assembly and tightening are provided for slip-critical and direct tension connections. It has repeatedly been demonstrated in the laboratory that each of the four installation methods provides the specified pretension when used properly with specified fasteners in good condition, but improperly applied methods or understrength fasteners or fasteners in poor condition provide uncertain pretensions. Therefore, regardless of the method used and prior to the commencement of work, it is required to be demonstrated by installation of a representative sample of the fastener assemblies in the tension calibrator that the specified pretension can be achieved using the procedure to be used with the fasteners to be used by the crews who will be doing the work.

With any of the four described tensioning methods, it is important to install bolts in all holes of the connection and bring them to an intermediate level of tension generally corresponding to snug tight in order to compact the joint. Even after being fully tightened, some thick parts with uneven surfaces may not be in contact over the entire faying surface. In itself, this is not detrimental to the performance of the joint. As long as the specified bolt tension is present in all bolts of the completed connection, the clamping force equal to the total of the tensions in all bolts will be transferred at the locations that are in contact and be fully effective in resisting slip through friction. If however, individual bolts are installed and tightened in a single continous operation, bolts which are tightened first will be subsequently relaxed by the tightening of the adjacent bolts. The total of the forces in all bolts will be reduced, which will reduce the slip load whether there is uninterrupted contact between the surfaces or not.

With all methods, tightening should begin at the most rigidly fixed or stiffest point and progress toward the free edges, both in the initial snugging up and in the final tightening.

Turn-of-Nut-Tightening. When properly implemented, turn-of-nut method provides more uniform tension in the bolts than does torque controlled tensioning methods because it is primarily dependent upon bolt elongation into the inelastic range.

Consistency and reliability method is dependent upon ensuring that the joint is well compacted and all bolts are uniformly tight at a snug tight condition prior to application of the final required partial turn. Under-tightened bolts will result if this starting condition is not achieved because subsequent turning of the nut will first close the gap before meaningful elongation of the bolt occurs as would be the case with solid steel in the grip. Reliability is also dependent upon ensuring that the turn that is applied is relative between the bolt and nut; thus the element not turned in tightening should be prevented from rotating while the required degree of turn is applied to the turned element. Reliability and inspectability of the method may be improved by having the outer face of the nut match-marked to the protruding end of the bolt after the joint has been snug tightened but prior to final tightening. Such marks may be applied by the wrench operator using a crayon or dab of paint. Such marks in their relatively displaced position after tightening will afford the inspector a means for noting the rotation that was applied.

Problems with turn-of-nut tightening have been encountered with hot-dip galvanized bolts. In some cases, the problems have been attributed to especially effective lubricant applied by the manufacturer to ensure that bolts from stock will meet the ASTM Specification requirements without the need for relubricating and retesting. Job site tests in the tension indicating device demonstrated the lubricant reduced the coefficient of friction between the bolt and nut to the degree that "the full effort of a man using an ordinary spud wrench" to snug tighten the joint actually induced the full required tension. Also, because the nuts could be removed by an ordinary spud wrench they were erroneously judged improperly tightened by the inspector. Research (see note 3) confirms that lubricated high-strength bolts may require only one-half as much torque to induce the specified tension. In other cases of problems with hot-dip galvanized bolts, the absence of lubrication or lack of proper overtapping caused seizing of the nut and bolt threads which resulted in twist failure of the bolt at less than specified tension. For such situations, use of a tension indicating device and the fasteners being installed may be helpful in establishing either the need for lubrication or alternate criteria for snug tight at about one-half the tension required by Table 4.

Because reliability of the method is independent of the presence or absence of washers, washers are not required except for oversize and slotted holes in an outer ply. In the absence of washers, testing after the fact using a torque wrench method is highly unreliable.

That is, the turn-of-nut method of installation, properly applied, is more reliable and consistent than the testing method. The best method for inspection of the method is for the Inspector to observe the required job site confirmation testing of the fasteners and the method to be used, followed by monitoring of the work in progress to ensure that the method is routinely properly applied.

Calibrated Wrench Method. Research has demonstrated that scatter in induced tension is to be expected when torque is used as an indirect indicator of tension. Numerous variables, which are not related to tension, affect torque. For example, the finish and tolerance on bolt threads, the finish and tolerance on the nut threads, the fact that the bolt and nut may not be produced by the same manufacturer, the degree of lubrication, the job site conditions contributing to dust and dirt or corrosion on the threads, the friction that exists to varying degree between the turned element and the supporting surface, the variability of the air pressure on the torque wrenches due to length of air lines or number of wrenches operating from the same source, the condition and lubrication of the wrench which may change within a work shift, and other factors all bear upon the effectiveness of the calibrated torque wrench to induce tension.

Recognition of the calibrated wrench method of tightening was removed from the Specification with the 1980 edition. This action was taken because it is the least reliable of all methods of installation and many costly controversies had occured. It is suspected that shortcut procedures in the use of the calibrated wrench method of installation, not in accordance with the Specification provisions, were probably being used. Further, torque controlled inspection procedures based upon "standard" or calculated inspection torques rather than torques determined as required by the Specification were being routinely used. These incorrect procedures plus others had a compounding effect upon the uncertainty of the installed bolt tension, and were responsible for many of the controversies.

It is recognized, however, that if the calibrated wrench method is implemented without shortcuts as intended by the Specification, that there will be a 90 percent assurance that the tensions specified in Table 4 will be equaled or exceeded. Because the Specification should not prohibit any method which will give acceptable results when used as specified, the calibrated wrench method of installation was reinstated in the 1985 edition of the Council Specification. However, to improve upon the previous situation, the 1985 version of the Specification was modified to require better control. Wrenches must be calibrated daily for each diameter and grade of bolt. Hardened washers must be used. Fasteners must be protected from dirt and moisture at the job site. Additionally, to achieve reliable results attention should be given to the control, insofar as it is practical, of those controllable factors which contribute to variability. For example, bolts and nuts should be purchased from reliable manufacturers with a record of good quality control to minimize the variabilty of the fit. Bolts and nuts should be adequately and uniformly lubricated. Water soluble lubricants should be avoided.

Installation of Alternative Design Fasteners. It is the policy of the Council to recognize only fasteners covered by ASTM Specifications; however, it cannot be denied that a general type of alternative design fastener, produced by several manufacturers, is used on a significant number of projects as permitted by Section2(d). The bolts referred to involve a splined end extending beyond the threaded portion of the bolt which is gripped by a specially designed wrench chuck which provides a means for turning the nut relative to the bolt. While such bolts are subject to many of the variables affecting torque mentioned in the preceding section, they are produced and shipped by the manufacturers as a nut-bolt assembly under good quality control, which apparently minimizes some of the negative aspects of the torque controlled process.

While these alternative design fasteners have been demonstrated to consistently provide tension in the fastener meeting the requirements of Table 5 in controlled tests in tension indicating devices, it must be recognized that the fastener may be misused and provide results as unreliable as those with other methods. They must be used in the as-delivered clean lubricated condition. The requirements of this Specification and the installation requirements of the manufacturer's specification required by Section 2(d) must be adhered to.

As with other methods, a representative sample of the bolts to be used should be tested to ensure that, when used in accordance with the manufacturer's instructions, they do, in fact, provide tension, as specified in Table 5. In the actual joints, bolts must be installed in all holes of a connection and all fasteners tightened to an intermediate level of tension adequate to pull all material into contact. Only after this has been accomplished should the fasteners be fully tensioned in a systematic manner and the splined end sheared off. The sheared off splined end merely signifies that at some time the bolt has been subjected to a torque adequate to cause the shearing. If the fasteners are installed and tensioned in a single continuous operation, they will give a misleading indication to the Inspector that the bolts are properly tightened. Therefore, the only way to inspect these fasteners with assurance is to observe the job site testing of the fasteners and installation procedure and then monitor the work while in progress to ensure that the specified procedure is routinely followed.

Direct Tension Indicator Tightening. This Specification recognizes load indicating devices covered by the American Society for Testing and Materials' "Specification for Compressible-Washer Type Direct Tension Indicators For Use With Structural Fasteners," ASTM F959, in Section 2(f). The referenced device is a hardened washer incorporating several small formed arches which are designed to deform in a controlled manner when subjected to load. These load indicator washers are the sole type of device known which is directly dependent upon the tension load in the bolt, rather than upon some indirect parameter, to indicate the tension in a bolt.

As with the alternative design load indicating bolts, load indicating washers are dependent upon the quality control of the producer and proper use in accordance with the manufacturer's installation procedures and these Specifications. If the load indicator washers delivered for use in a specific application are tested at the job site to demonstrate that all components of the assembly do provide a proper indication of bolt tension, they are reliable if they are properly used by the bolting crews. Direct tension indicators meeting the requirements of ASTM F959 depend upon tension in the fastener to cause inelastic deformation of the formed arches. Bolts together with the load indicator washer plus any other washers required by Specification should be installed in all holes of the connection and the bolts tightened to approximately one-half the specified tension (deformation of the formed arches by about one-half the amount required to compress them to the specified gap) to ensure that plies of the joint have been brought into firm contact. Only after this initial tightening operation should the bolts be fully tensioned in a systematic manner. If the bolts are installed and tensioned in a single continuous operation, the load indicator washers will give the inspector a misleading indication that bolts are uniformly tensioned to the specified tension. Therefore, the only way to inspect fasteners with which load indicator washers are used with assurance is to observe the job site testing of the devices and installation procedure and then routinely monitor the work while in progress to ensure that the specified procedure is followed.

Use of direct tension indicators provides a reliable means for tensioning galvanized fasteners because it avoids the factors which affect other methods.

During installation, care must be taken to ensure that the indicator nubs are oriented to bear against the hardened bearing surface of the bolt head or against a hardened flat washer if used under the nut.

C9 Inspection

It is apparent from the commentary on installation procedures that the inspection procedures giving the best assurance that bolts are properly installed and tensioned is provided by Inspector observation of the calibration testing of the fasteners using the selected installation procedure followed by monitoring of the work in progress to ensure that the procedure that was demonstrated to provide the specified tension is routinely adhered to. When such a program is followed, no further evidence of proper bolt tension is required.

If testing for bolt tension using torque wrenches is conducted subsequent to the time the work of installation and tightening of bolts performed, the test procedure is subject to all of the uncertainties of torque controlled calibrated wrench installation. Additionally, the absence of many of the controls necessary to minimize variability of the torque to tension relationship, which are unnecessary for the other methods of bolt installation, such as use of hardened washers, careful attention to lubrication and the uncertainty of the effect of passage of time and exposure in the installed condition all reduce the reliability of the arbitration inspection results. The fact that in many cases it may have to be based upon a job test torque determined by using bolts only assumed to be representative of the bolts in the actual job, or using bolts removed from completed joints, makes the test procedure less reliable than a properly implemented installation procedure it is used to verify. Verification inspection using ultrasonic extensometers is accurate but costly and time-consuming, and requires that each tested bolt must be loosened to zero tension for calibration. Therefore, extensometers should be used for inspection only in the most critical cases. The arbitration inspection procedure contained in the Specification is provided, in spite of its limitations, as the most feasible available at this time.

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