Bolting
Section 11

High Strength Structural Bolting
What Is High Strength Bolting & Why Is It Important?

- A325 or A490 Bolts are tightened to a prescribed tension to produce enough Friction force in a connection to resist imposed loads.

- Slip Critical Connections do not rely on the bearing between the bolt and plate material to transfer loads. They rely on the Friction of the plates. The bolts just pull the plates together thereby increasing the friction on the plates.

Bolt Properties
High Strength Field Bolting Theory & Behavior

A325 Load/Elongation Curve

Bolt Types:

A325 – High Strength Bolts for Structural Steel Joints (Most common bolt type)

A490 – Heat Treated Steel Structural Bolts (Used by exception only)

A307 – Carbon Steel Bolts (NOT USED IN HIGH STRENGTH BOLTING APPLICATIONS)
High Strength Field Bolting

A325 Bolt Types:
- Type 1 (Medium Carbon) 1/2” to 1 1/2”
- Type 3 (Weathering) 1/2” to 1 1/2”

A325 Strength Requirements:

<table>
<thead>
<tr>
<th>Diameter (in.)</th>
<th>Yield (ksi)</th>
<th>Tensile (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2” - 1”</td>
<td>92</td>
<td>120</td>
</tr>
<tr>
<td>1 1/8” - 1 1/2”</td>
<td>81</td>
<td>105</td>
</tr>
</tbody>
</table>

Bolt Type Matching Nut

<table>
<thead>
<tr>
<th>Bolt Type</th>
<th>Matching Nut</th>
</tr>
</thead>
<tbody>
<tr>
<td>A325 Type 1 (Plain)</td>
<td>C, D, DH</td>
</tr>
<tr>
<td></td>
<td>DH</td>
</tr>
<tr>
<td>Type 1 (Galvanized)</td>
<td>C3, DH3</td>
</tr>
</tbody>
</table>

Note: All Nuts For High Strength Fasteners are **Heavy Hex**.

Non Heat Treated Nuts: Proof Load Stress = 150 ksi
Heat Treated Nuts: Proof Load Stress = 175 ksi
High Strength Field Bolting

Hardened Steel Washers:

- ASTM F436
- Type 1 – Carbon Steel (Plain or Galvanized)
- Type 3 – Weathering Steel
- Rockwell Hard. Values: 38 to 45 (Plain) - 170 ksi
  26 to 45 (Galvanized) - 125 ksi

Methods of Tightening
Methods of Tightening

- Turn of Nut Method
- Direct Tension Indicators (DTI’s)
- Tension Control Fasteners

Steel Girder Construction

- Most splice and connection bolts on our girders are installed using the Turn-of-Nut Method.
- DTI’s are not used.
- TC bolts are used some.
Field Tests

Field Tests At The Project Site

• Rotational Capacity Test

• Verification Test

• Inspection Torque
Long Bolt Summary

Short Bolt Summary
Rotational Capacity Test for Long Bolts

View Rotational Capacity Test for Long Bolts
Rotational-Capacity Test Equipment

- Skidmore-Wilhelm or Equivalent
  - Calibrated Yearly

- Standard Torque Wrench
  - 1000 ft. lb. Capacity
  - Calibrated Yearly

- Rigid Steel Joint
  - Short Bolt Fasteners
Rotational Capacity Test For Long Bolt Method

Table 560-1
A325 Bolts

Note: A490 Bolts require higher tensions
Ro-Cap Test for Long Bolts

1. Sample 2 Bolt/Washer/Nut Assemblies
2. Assemble fastener with 3-5 threads within grip
3. Snug tight (10% of req’d fast. tension, Table 560-1)
   (Tolerance= -0 kips to +2 kips)
4. Mark socket
5. Tighten to req’d fast. tension and record torque
   (torque must not exceed T=0.25PD) (P in lbs, D in ft)
6. Turn nut to twice the rotation in Table 560-3 (tension
   must exceed 115% of req’d fast. tension)

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Table 560-3

<table>
<thead>
<tr>
<th>Bolt Length (underide of head to end of bolt)</th>
<th>Both faces normal to bolt axis</th>
<th>One face normal to bolt axis and other sloped not more than 1:20 (beveled washer not used)</th>
<th>Both faces sloped not more than 1:20 from normal to bolt axis (beveled washer not used)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to and including 4 diameters</td>
<td>1/2 turn</td>
<td>1/2 turn</td>
<td>2/3 turn</td>
</tr>
<tr>
<td>Over 4 diameters</td>
<td>1/2 turn</td>
<td>2/3 turn</td>
<td>5/6 turn</td>
</tr>
<tr>
<td>but not exceeding 8 diameters</td>
<td>2/3 turn</td>
<td>5/6 turn</td>
<td>1 turn</td>
</tr>
<tr>
<td>Over 8 diameters</td>
<td>2/3 turn</td>
<td>5/6 turn</td>
<td>1 turn</td>
</tr>
<tr>
<td>but not exceeding 12 diameters</td>
<td>2/3 turn</td>
<td>5/6 turn</td>
<td>1 turn</td>
</tr>
</tbody>
</table>

1. Nut rotation is relative to bolt, regardless of the element (nut or bolt) being turned. For bolts installed by one-half turn and less, the tolerance shall be plus or minus 30°; for bolts installed by two-thirds turn and more, the tolerance shall be plus or minus 45°.
2. No research has been performed by the Research Council on Structural Connections to establish the turn-off-out procedure for bolt lengths exceeding 12 diameters. Therefore, the required rotation shall be determined by actual test in a suitable tension measuring device according to 0560.296-9-10-05.
Skidmore/Wilhelm

Change Plate to Correct Hole Size
Correct Size Plate Installed

Bolt Head Insert On Backside
3 - 5 Threads in Grip

3 to 5 threads in grip

one washer minimum

washers or shims
Added Washers to Maintain 3-5 Threads Within Grip

Snug Tight
(10% of Required Fastener Tension)
Table 560-1

Rotational Capacity Test
Snug Tight (Long Bolts)

<table>
<thead>
<tr>
<th>Bolt Diameter</th>
<th>Required Fastener Tension (Table 560-1)</th>
<th>Required Fastener Tension</th>
<th>Snug Tight (10% Req’d. Fast. Tens.)</th>
<th>Snug Tight</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4”</td>
<td>28 kips</td>
<td>28,000 lbs.</td>
<td>0.10 (28,000 lbs)</td>
<td>2,800 lbs</td>
<td>- 0 kips to + 2 kips</td>
</tr>
</tbody>
</table>
Mark Bolt, Nut & Plate

Mark Bolt, Nut & Plate
Tighten to Req’d Fastener Tension

Record Torque
**Rotational Capacity Test**

**Maximum Torque, T=0.25 PD**

- **Diameter**: 3/4”
- **Required Fastener Tension (Table 560-1)**: 28 kips

Max. Torque, \( T = 0.25 \times PD \)  
(P in lbs, D in ft)

Max. Torque, \( T = 0.25(28,000 \text{ lbs})(3/4”)(1 \text{ ft}/12”) = 438 \text{ ft-lbs} \)

**Max. Torque, T = 438 ft-lbs**

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**Turn Nut to Twice the Rotation**

- **Turn Nut**: Twice Rotation Specified in Table 560-3
Rotation Example

What is the turn requirement in the rotational capacity test for a bolt with a diameter = 7/8” and a bolt length = 6”?

4 Diameters = 4 (7/8”) = 3.5”
8 Diameters = 8 (7/8”) = 7”

Single turn requirement from Table 560-3 = 1/2 turn
Twice rotation = 2 (1/2 turn) = 1 full turn
Rotation Exercise

What is the turn requirement in the rotational capacity test for a bolt with a diameter = 3/4” and a bolt length = 3”?

Rotation Exercise Key

What is the turn requirement in the rotational capacity test for a bolt with a diameter = 3/4” and a bolt length = 3”?

4 Diameters = 4 (3/4”) = 3”
8 Diameters = 8 (3/4”) = 6”

Single turn requirement from Table 560-3 = 1/3 turn
Twice rotation = 2 (1/3 turn) = 2/3 turn
Tension Must Exceed 115% of Req’d Fastener Tension

Minimum Tension Example

What is the minimum tension required for a 3/4” bolt during the Rotational Capacity Test when the nut is turned to twice the turn shown in Table 560-3?

Min. Tension = 115% of Required Fastener Tension (Table 560-1)

Min. Tension = 1.15 (28,000 lbs.)

Min. Tension = 32,200 lbs.
Examine Bolt and Nut

Reject assemblies showing thread stripping or torsional failure. Elongation of the threads in the grip is normal.

Rotational Capacity Test for Short Bolts
View Short Bolt Video

High Strength Bolting
Short Bolt Method
Rotational Capacity Test For Short Bolt Method

Ro-Cap Test for Short Bolts

1. Sample 2 Bolt/Washer/Nut Assemblies
2. Assemble fastener with 3-5 threads within grip
3. Snug tight (10% of max allowable torque < Torque < 20% of MAT, MAT=1.15(0.25PD)) (P in lbs, D in ft)
4. Mark nut (socket) relative to fixed bolt
5. Tighten nut to rotation in Table 560-3 and record torque (torque must not exceed 1.15 allowed torque)
6. Turn nut to twice the rotation in Table 560-3
Short Bolt Method

Verification Testing

Turn-of-Nut Method
Verification Test Long Bolt Method

Verification Testing for Long Bolts Turn-of-Nut Method

1. Sample 3 Bolt/Washer/Nut Assembles
2. Snug the bolt using method to be used on the structure
   
   (plies of joint in firm contact; full effort on 12” spud wrench)

   (10% of RFT < Tension < 50% of RFT)
3. Mark the Bolt/Nut/Plate
4. Tighten nut to rotation in Table 560-3
5. Verify tension is 5% greater than proof load
### Turn-of-Nut Verification Testing
#### Long Bolt Example

<table>
<thead>
<tr>
<th>Diameter</th>
<th>3/4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>3&quot;</td>
</tr>
<tr>
<td>Required Rotation (Turns)</td>
<td>1/3</td>
</tr>
<tr>
<td>Required Fastener Tension</td>
<td>28,000 lbs</td>
</tr>
</tbody>
</table>

Req’d Verification Tension = (105%) Req’d Fast Tension

Req’d Verification Tension = (1.05)(28,000) = 29,400 lbs.

### Turn-of-Nut Verification Testing
#### Long Bolt Exercise

<table>
<thead>
<tr>
<th>Diameter</th>
<th>7/8&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>4&quot;</td>
</tr>
<tr>
<td>Required Rotation (Turns)</td>
<td>____________</td>
</tr>
<tr>
<td>Required Fastener Tension</td>
<td>____________ lbs</td>
</tr>
<tr>
<td>Req’d Verification Tension</td>
<td>_______________</td>
</tr>
</tbody>
</table>
Turn-of-Nut Verification Testing
Long Bolt Exercise Key

Diameter = 7/8"
Length = 4"
Required Rotation (Turns) = 1/2
Required Fastener Tension = 39,000 lbs

Req’d Verification Tension = (105%) Req’d Fast Tension
Req’d Verification Tension = (1.05)(39,000) = 40,950 lbs.

Verification Test Short Bolt Method
Verification Testing for Short Bolts Turn-of-Nut Method

1. Sample 3 Bolt/Washer/Nut Assembles
2. Snug the bolt using method to be used on the structure
   (plies of joint in firm contact; full effort on 12" spud wrench)
   (10% of MAT < Torque < 50% of MAT)
3. Mark the Bolt/Nut/Plate
4. Tighten nut to rotation in Table 560-3
5. Verify torque is 5% greater than recorded torque at turn requirement

Marked Bolt Connection
Nuts Turned $\frac{1}{2}$ Turn

Inspection Torque

Turn-of-Nut Method
Inspection Torque For Long Bolt Method

1. Sample 3 Bolt/Washer/Nut assembles
2. Place in skidmore and tighten to required tension in Table 560-1
3. Measure torque required to turn the nut 5 degrees (1” @ 12” radius)
4. Inspection torque is the average of the 3 tests
Inspection Torque For Short Bolt Method

1. Sample 3 Bolt/Washer/Nut assembles
2. Snug tight (10% of MAT < Torque < 20% of MAT)
   Maximum Allowable Torque = 1.15(0.25)PD)
3. Mark the Bolt/Nut/Plate
4. Tighten nut to rotation in Table 560-3
5. Measure torque required to turn the nut 5 degrees
   (1” @ 12” radius)
6. Inspection torque is the average of the 3 tests
Field Inspection

Turn-of-Nut Method

– Select at random 10% of the tensioned bolts (2 minimum) in each connection.
– Apply Inspection Torque. If none turn, the connection passes.
– If one or more fasteners turn, job torque the remaining fasteners in the connection.
– Re-tension and inspect all fasteners that turned for minimum Inspection Torque.
Field Inspection Cont’d

- Nut Turned to Rotation in Table 560-3
- +/- 30° for 1/3 & 1/2 turns

High Strength Field Bolting All Applications

- Non-galvanized fasteners may be reused once.
- Galvanized fasteners may not be reused.
- Previously tightened fasteners, loosened by tightening of adjacent fasteners will not be considered a re-use.
Bolt Installation
(00560.46 (g))

- 25% Drift Pins
- 25% Fit Up Bolts

Systematic Tightening
Bolts in water?

Nuts in water?
Bolt Exercise

Bolt Diameter = 3/4”
Bolt Length = 5”
Measured Torque @ Req’d Fast. Tens. = 350 ft.-lbs.
Measured Tension @ 2x Rotation = 45,000 lbs.

Complete Ro-Cap Sample 1 on the Rotational Capacity Test Form for Long Bolts.
Table 560-3

Bolt Exercise Key

Required Fastener Tension = 28,000 lbs.
Snug Tight = 3,000 lbs.
Measured Torque = 350 ft.-lbs.
Maximum Allowable Torque = 438 ft.-lbs.
Measured Tension = 45,000 lbs.
@ 1 full turn
Minimum Tension Required = 32,200 lbs.

Sample 1 Results: Pass
Other Types Of Bolt Situations

Traffic Signal & Illumination Supports (00962)
TM629 General Note

Tighten anchor bolts and arm connection bolts according to 00962.46(j)(2).
21. Tighten 4 bolt arm connection bolts and tighten anchor rods in accordance with 962.46(j)(2).

22. Tighten 8 bolt arm connection bolts in accordance with 930.40(d).
Tightening Requirements
(00962.46(j)(2)(a&d))

- Snug Tight (All plies in firm contact & full effort on the end of 12” spud wrench)

Past Snug Tight

- ASTM A 307 Anchor Rods 1/12 Turn
- ASTM A 449 Anchor Rods 1/6 Turn
- ASTM F 1554 Gr 55 Anchor Rd 1/6 Turn
- ASTM A 325 Bolts 1/6 Turn
Sign Supports (00930)
Major Sign Supports
00930.10

- Rotational Capacity Test Required At Job Site
- Except for minor sign supports

TM623
**TM623 General Notes**

All High Strength Bolts shall be considered slip critical and tightened according to 00930.40(d)(2)a unless otherwise noted.

**Slip Critical Connections 00930.40 (d)(2)(a)**

- Install New DTI’s
- Snug Tight All
- Tighten To Full Refusal of .005 Feeler Gauge (SP00930.42(d)(2)(a))
For Anchor Rods:

- Lubricate top nuts
- Snug tight top nuts (full effort on 12” wrench)
- Snug tight bottom nuts
- Tighten all top nuts an additional 1/6 turn in two passes (1/12 turn per pass)
Cantilevered Sign Base

Resin Bonded Anchor Systems
00535
Resin Bonded Anchor System
Tightening Requirements
00535.40

• Tighten to ¼ turn past snug tight

Resin Bonded Anchor System
Test Requirements
SP00535.45

• 3 Test Anchors Prior To Production
• Test To 80% of Table 535-1 Values (For Tension Application)
• Test To 50% of Table 535-1 Values (For Shear Application)
• Test 10% of Production or as Approved By EOR (Depends on Location)
<table>
<thead>
<tr>
<th>Dia. (inch)</th>
<th>Anchor Bolts</th>
<th>Rebar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 36</td>
<td>Grade 55</td>
</tr>
<tr>
<td></td>
<td>Force (Pounds)</td>
<td>Force (Pounds)</td>
</tr>
<tr>
<td>1/2</td>
<td>7,400</td>
<td>9,700</td>
</tr>
<tr>
<td>5/8</td>
<td>11,700</td>
<td>16,900</td>
</tr>
<tr>
<td>3/4</td>
<td>17,300</td>
<td>22,500</td>
</tr>
<tr>
<td>7/8</td>
<td>24,000</td>
<td>31,200</td>
</tr>
<tr>
<td>1</td>
<td>31,700</td>
<td>40,900</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>