FASTENER FUNDAMENTALS

Chad Larson
Vice President
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Course Description

Fastener Fundamentals

January 23, 2014

Structural fasteners are a critical part of most steel structures. This webinar will cover a broad range of topics including fastener strength, selection criteria, available coatings and testing. This overview will go beyond the standards and specifications and provide users and specifiers with helpful background information and intent, as well as practical strategies to keep projects trouble free.

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Learning Objectives

- Gain an understanding of the basics of bolting.
- Gain an understanding of the background and intent of standards and specifications for fasteners.
- Become familiar with fastener coatings and testing.
- Gain an understanding of practical design strategies for fasteners.

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ABOUT THE PRESENTER

Chad Larson

- 25 years in fastener manufacturing and distribution with an emphasis on continuous improvement
- Background in production, quality, sales and management
- Former RCSC/ASTM Liaison
- Former Secretary/Treasurer of the Research Council on Structural Connections
- Vice Chair of ASTM F16 Fastener Committee
- Chair of ASTM F16.02 – Bolt, Nut, Washer Subcommittee
- Chair of the F16.02.02 Structural Bolt Task Group
- Chair of the Rotational Capacity Testing Task Group

What We Will Cover

- Why should you know more about bolts
- Organizations responsible for bolted connections
- How nuts and bolts are made – basics
- Bolting basics – rules of thumb
- Threads – understanding terms
- Shear
- Lubrication
- Bolt types
- Coatings
- Jobsite requirements - basic
- Installation methods - overview
- Rotational capacity testing

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What We Will Not Cover

- Hydrogen embrittlement
- Stress corrosion cracking
- Fatigue
- Deformation or embedment
- Prying action
- Load reversal or compressive forces
- Heat Treatment
- Hole sizes
- Washer requirements
- Inspection methods
- Arbitration inspection

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Forces on a Bolted Connection

- See Geoff Kulak's presentation - AISC
  - http://www.aisc.org/content.aspx?id=4502

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Why You Should Know…

- Understanding bolts will help you make more informed engineering decisions
- Understanding bolts will help make your intentions and requirements clear downstream
- Making informed decisions will decrease the likelihood of problems down the road
- Preventing problems prevents compromise

- The difference between panic and understanding is slight, but can mean thousands of dollars
- Your intentions do not always make it to the project

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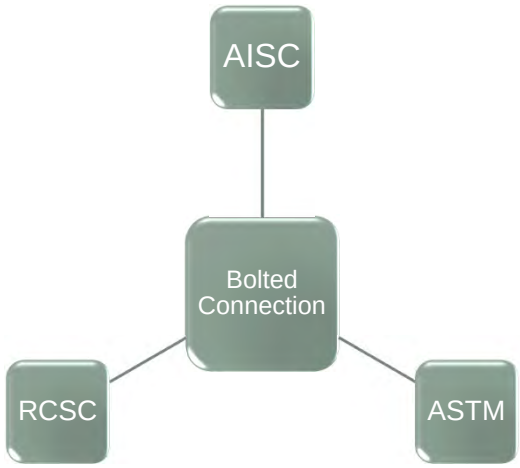
IT TAKES AN ARMY

Bolted Connection



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Organizations

- AISC – American Institute of Steel Construction
  - Not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities…
  - Research
  - Standardize
  - Educate
  - Promote

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Organizations

- RCSC – Research Council on Structural Connections
  - The RCSC is a non-profit, volunteer organization, comprised of over 90 leading experts in the fields of structural steel connection design, engineering, fabrication, erection and bolting. Research projects funded by the RCSC serve to provide safety, reliability, and standard practice for the steel construction industry throughout the world.
  - Research
  - Convert research to practical application
  - "Specification for Structural Joints Using High-Strength Bolts"
  - Can be found in your AISC manual, at http://aisc.org/freepubs or at http://boltcouncil.org/files/2009RCSCSpecification.pdf

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Organizations

- ASTM International – Formerly known as American Society of Testing and Materials
  - Globally recognized leader in the development and delivery of international voluntary consensus standards. Today, some 12,000 ASTM standards are used around the world to improve product quality, enhance safety, facilitate market access and trade, and build consumer confidence.
  - F16 Fastener Committee is 225 of the 30,000 ASTM members.
    - Maintain Structural Bolt, Nut, Washer and related standards
  - All Volunteer
  - No Technical Staff

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Organizations

- ASTM and RCSC are all volunteer
- Are never aligned in real time
- A number of errors in ASTM structural bolt standards, updates and balloting take a long time

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HOW ARE BOLTS AND NUTS MADE?

Typical Cold Forming Progression

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Cold Forming

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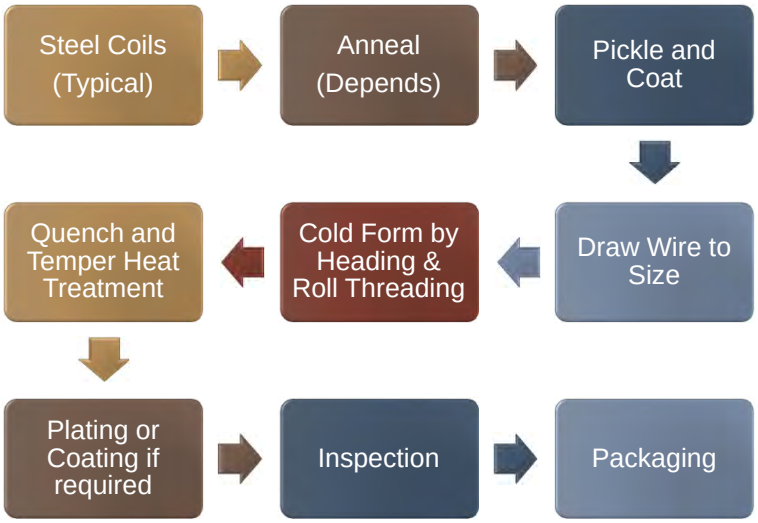
Cold Forming Progression



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Cold Forming

- http://youtu.be/3kxcw08p_oY
- Cold Forming
  - Good for high volume runs, often highly automated
  - Typically done on 4 or 5 station high speed cold forming machines, with 60 to 120 ppm typical
  - Expensive tooling
  - Long changeover time
  - Generally very good tolerance control
  - Generally longer tool life than hot forging
  - Almost always rolled threads
  - Generally cleaner surface finish

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Bolt Hot Forging

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Hot Forging/Forming

- Hot Forging/Hot Forming
  - Better for low volume runs, large diameters or long lengths
  - High temperature via electric induction heaters or gas
  - Hot forged bolts more likely to have seams, fins or swells
  - Hot forged bolts more likely to have cut threads, but rolled threads are available from many manufacturers
  - In most instances hot forging is a very manual process
  - Greater range of diameters and lengths available with hot forging
  - Bolts often made from blanks to speed delivery
  - Some mill and heat scale

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Thread Rolling

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How Are Nuts Made?

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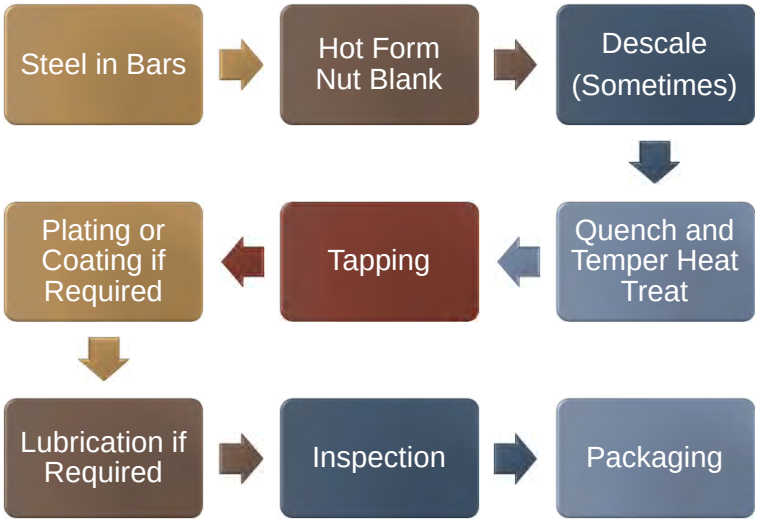
Hot Forming Progression



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BOLTING BASICS

Things you should understand

Terms

- **Clamp Force:** the cumulative compressive force between joint members due to the tensile force created in tightened fasteners
- **Elastic Interaction:** in a bolted joint with multiple fasteners, variation in individual fastener preload due to tightening of the other fasteners
- **Embedment:** localized yielding of bolted joint components resulting in a change of grip length consequently causing relaxation of the bolted joint
- **Grip Length:** the combined thickness of all components joined together between the bolt head and nut
- **Nut Factor:** an empirically determined constant that models many variables, such as friction, that affect the torque-tension relationship.
- **Preload:** the tensile force developed during installation

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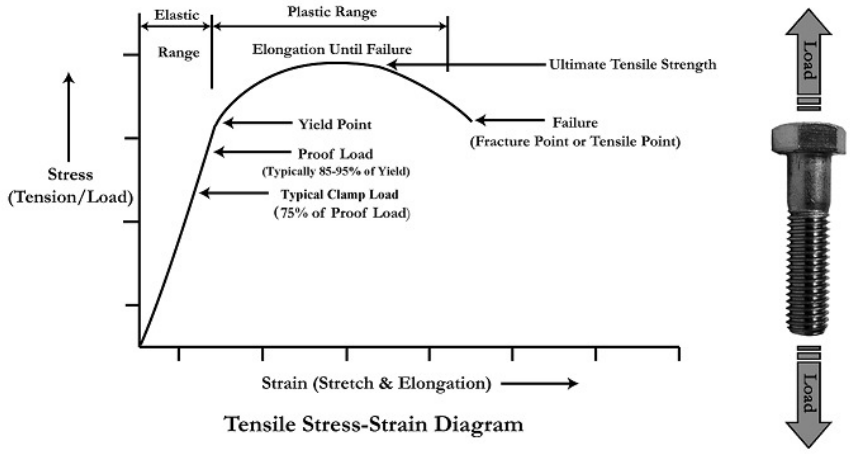
Understanding the Curve



Tensile Stress-Strain Diagram

Image courtesy of Fastenal

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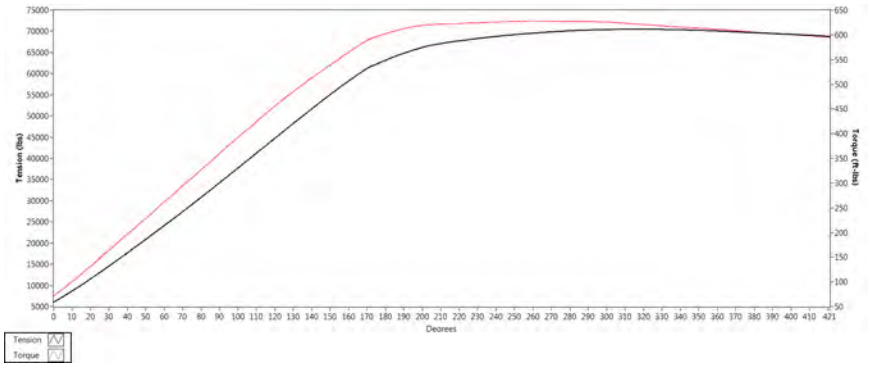
Torque – Tension – Angle Curve



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Bolting Basics

- Nuts should be stronger than bolts
- The more bolt threads in the grip the better, worry more about shank-out than stick-out
- Lubrication is essential to performance
- Torque can be a good indicator of tension if controlled
- Roll threaded bolts are stronger than cut threaded bolts
- Fine threaded bolts are stronger and more vibration resistant

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Bolting Basics

- Large parts are much more difficult to heat treat properly
- For large diameters be sure to consider die fins or possible body swells and hole size
- Long bolts can be difficult to keep straight, consider this when going through many thick plies
- Most stress on the first few nut threads nearest the grip
- Many quality problems are a result of poor heat treatment or thread quality/fit

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Torque is Valuable, but Complicated

- Torque is a great means of fit up and snugging
- Torque is very accurate when controlled
- Torque can provide very uniform loading
- Torque is wildly variable and cumbersome the way our industry uses it
- Torque when installing from the head can be quite different that torque when installing from the nut, how did you do your pre-installation test?

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THREADS

Bolt and Nut Threads

- There are over 120 elements to thread design
- Standards allow us to ignore most of those elements, but a few are important to understand
- Inch series structural bolts are always “Unified Coarse”, Class 2A tolerance
- Threads do not load evenly

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Threads Continued…

- Rolled threads can be 5 to 15 percent stronger, depending on the grade of fastener, but cut threads can meet specifications
- Many quality issues are the result of threads or functional thread fit
- Structural bolts have much shorter threads than standard cap screws

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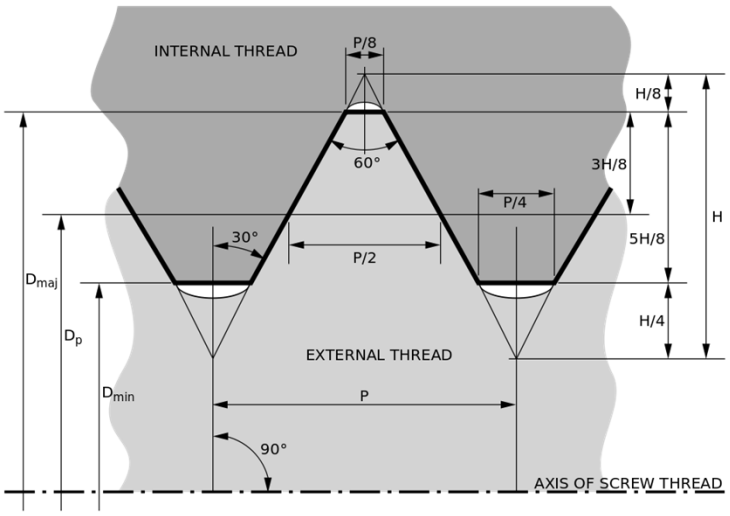
Understanding Threads



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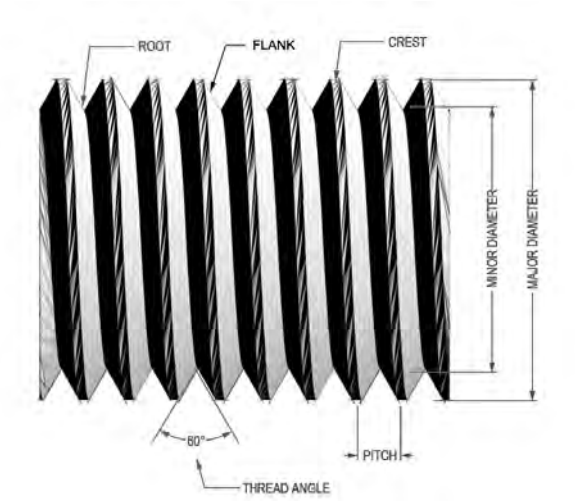
Basic Thread Terms



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Pitch vs. Pitch Diameter (P.D.)

- Pitch is simply thread spacing
  - Inch series in TPI or 7/8”-9 x 2” is 9 **T**hreads **P**er **I**nch
  - Metric series in individual spacing M22 x 2.5 x 40 is 2.5mm between threads
  - Ex. UNF is 7/8”-14 x 2”
  - Ex. UNC is 7/8”-9 x 2”
- Pitch does not equal fit
  - You cannot put a 1”-8 nut on a 2”-8 bolt

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Pitch vs. Pitch Diameter (P.D.)

- We need a means of determining the physical thread size for a given pitch (spacing) and nominal diameter
  - The thread pitch diameter is the diameter of a cylindrical surface, axially concentric to the thread, which intersects the thread flanks at equidistant points.
    - Diameter across threads from theoretic thread centerlines
  - Pitch diameter is the functional size of a given thread form
    - Many manufacturers do not measure pitch directly
    - Coatings significantly change pitch diameter but not pitch

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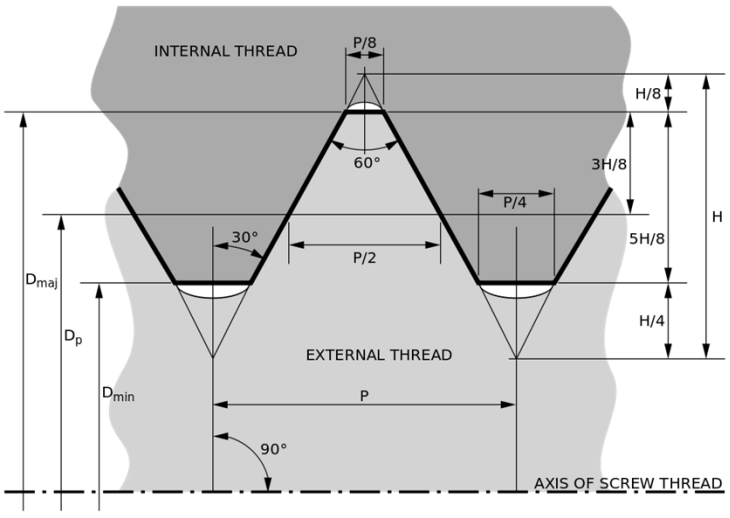
Understanding Threads



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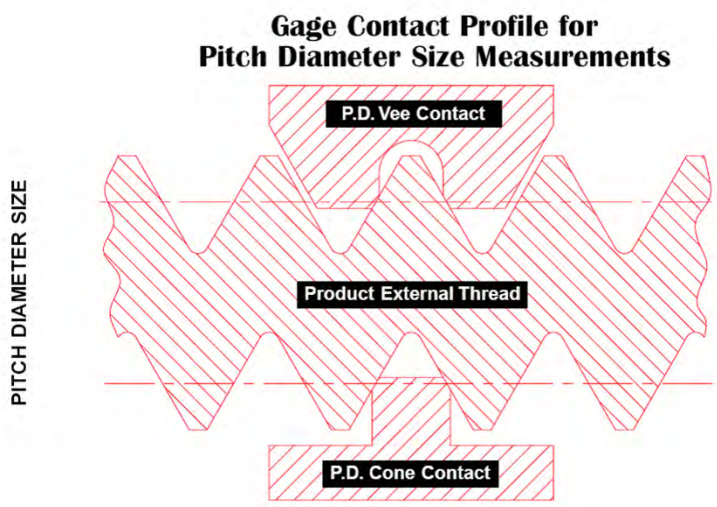
Understanding Thread PD



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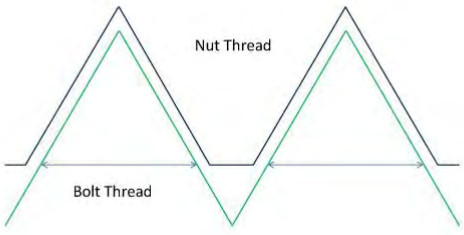
Thread Profile Standard Tap



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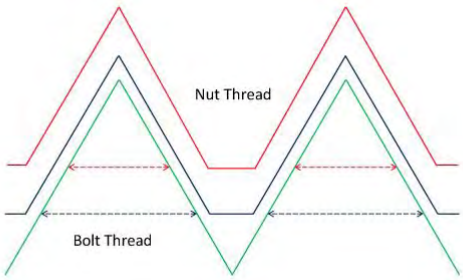
Thread Profile Over-Sized



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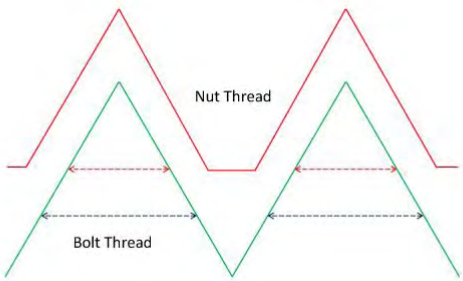
Thread Profile Over-Sized



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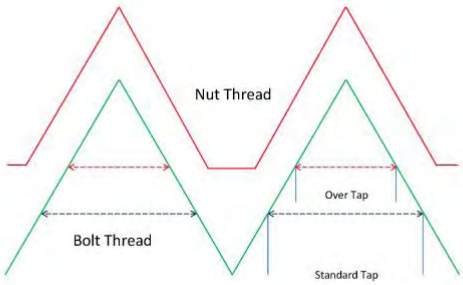
Thread Profile Over-Sized



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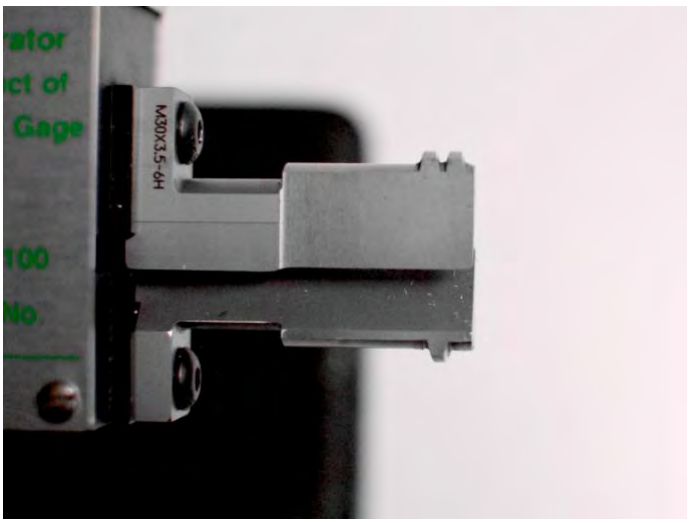
Single Point Measurement



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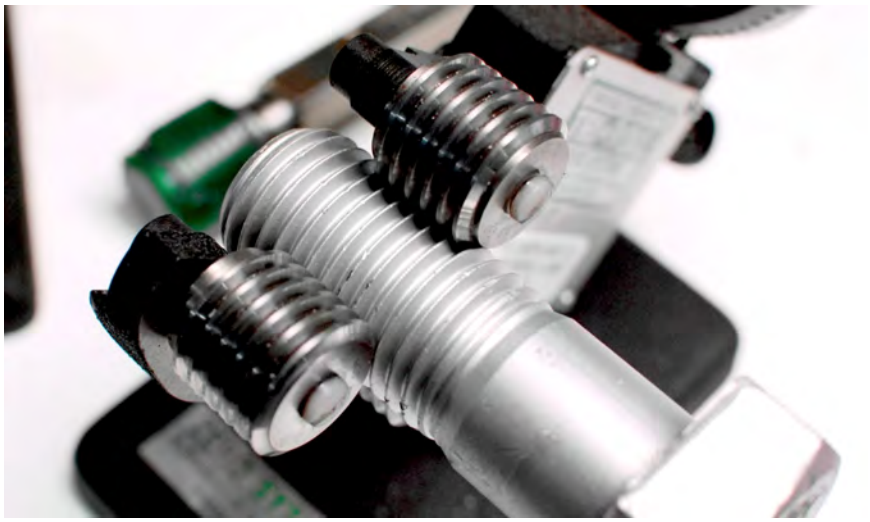
Multi Point Measurement



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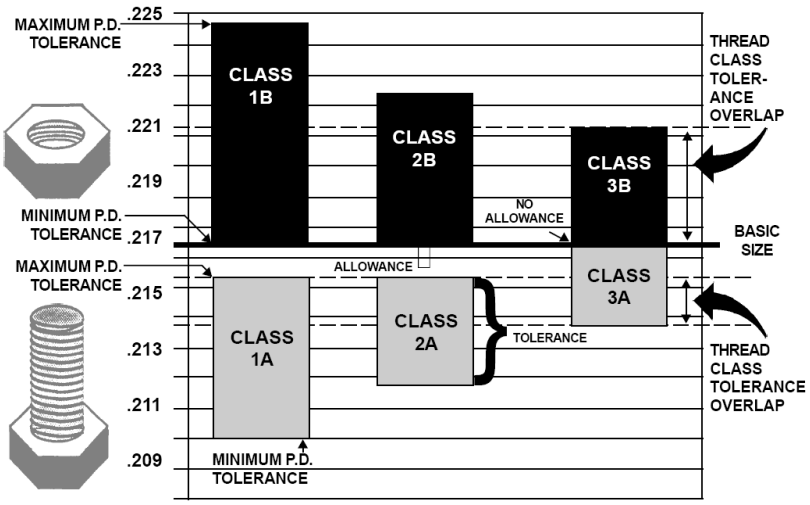
Thread Class



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Thread Lengths – Not All Equal

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Mating Components

Improperly mated

Improperly mated

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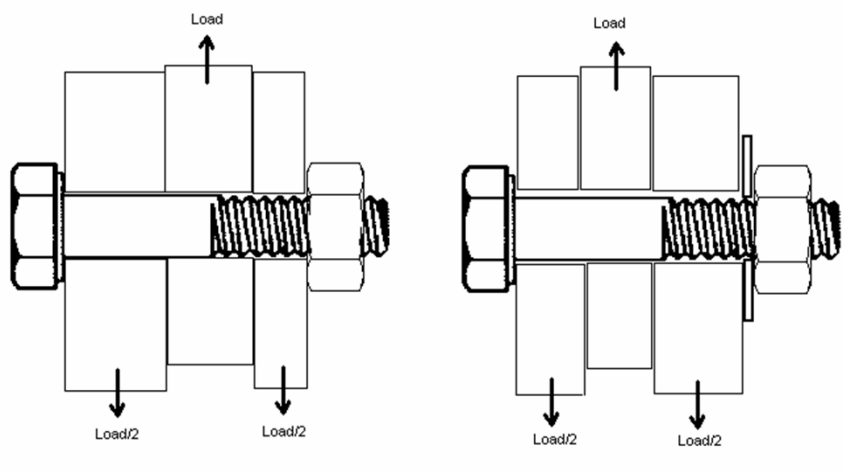
SHEAR

Understanding Shear



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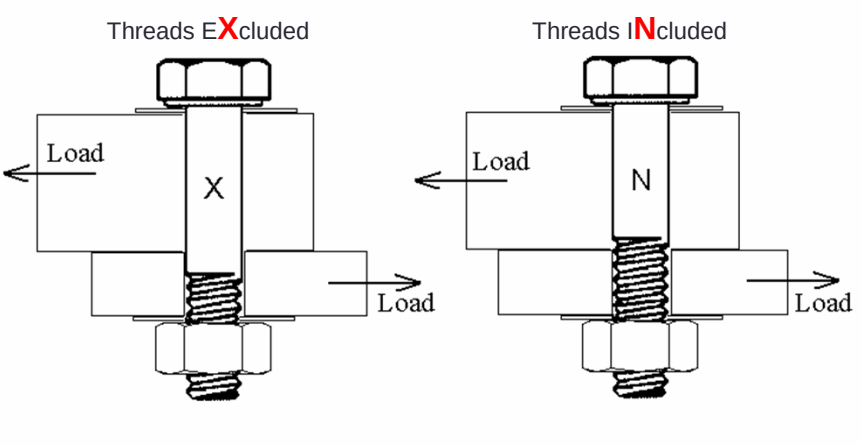
Understanding Shear



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LUBRICATION

Understanding the “K” or “Nut Factor”

"K"

- Within the elastic range, before permanent stretch, the relationship between torque and tension is linear
- Over 50 variables have an effect on this relationship: surface roughness, temperature, rate of installation, helix angle, stiffness, and humidity to name a few.

- Typical values for applications are:
  - K = 0.20 as-received bolts and nuts, no supplemental lubrication (This can be highly variable)
  - K = 0.10 to 0.17 bolts and nuts with wax or other lubricant
  - K = 0.28 bolts with HDG coating, no lubricant

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"K" Factor or Nut Factor

The friction relationship or K-factor between applied torque and the resulting fastener tension. The following formula can be used to get the K factor if the torque and tension are known.

K= T/N * 12/D

Where: K = K or nut factor
T = Torque
N = Bolt Tension
D = Nominal bolt diameter

Example: ¾" x 2" TC Bolt. 300 ft. lbs. torque at 35,000 lbs. clamp load.

K= (300/35000) * (12/.750) = .137

Solving for Torque the equation becomes T= KDN/12

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Lubrication

Bolt Dia. 0.75		K - Factor 0.09	K - Factor 0.11	K - Factor 0.13	K - Factor 0.15	K - Factor 0.17	K - Factor 0.19	K - Factor 0.21	K - Factor 0.23	K - Factor 0.25
Tension	1000	6	7	8	9	11	12	13	14	16
in lbs.	5000	28	34	41	47	53	59	66	72	78
	10000	56	69	81	94	106	119	131	144	156
	15000	84	103	122	141	159	178	197	216	234
	20000	113	138	163	188	213	238	263	288	313
	25000	141	172	203	234	266	297	328	359	391
	30000	169	206	244	281	319	356	394	431	469
	35000	197	241	284	328	372	416	459	503	547
	40000	225	275	325	375	425	475	525	575	625
	45000	253	309	366	422	478	534	591	647	703

Torque, ft./lbs.

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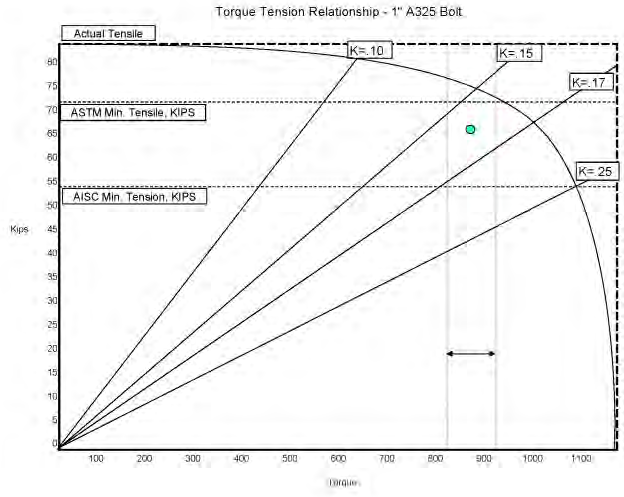
Lubrication or Coating "K" Factor



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Lubrication

Lubrication

Paint adhesion

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Lubrication

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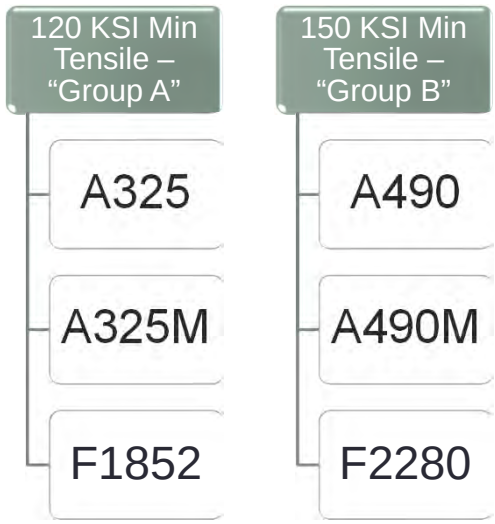
STRUCTURAL BOLTS

Structural Bolt Grades



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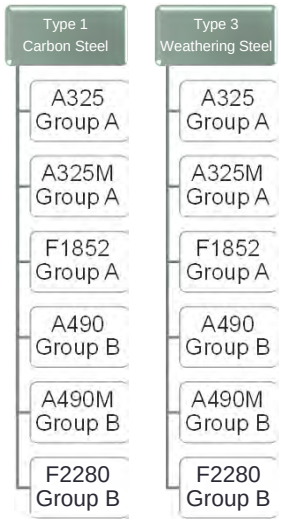
Structural Bolt Types



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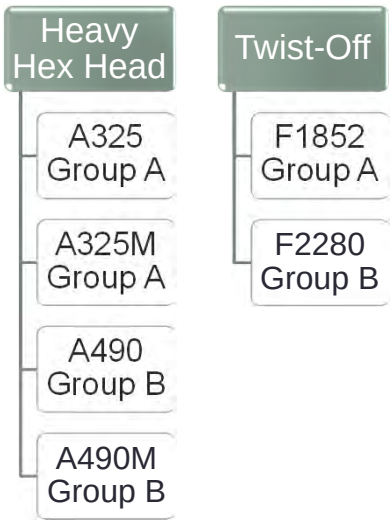
Structural Bolt Styles



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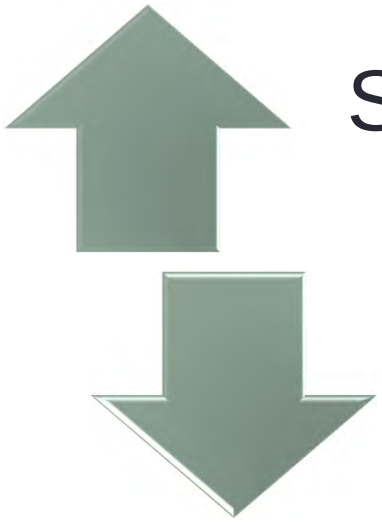
Structural Bolts



Strength

Ductility

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Structural Bolts

150 KSI
Group B

120 KSI
Group A

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Other Standards Used

- Heavy hex nuts
  - A563 Grade C, C3 - Group A, plain only
    - C3 for weathering applications
  - A563 Grade DH, DH3 - Group A or B, plain or coated
    - DH3 for weathering applications
- Washers
  - F436 T1 - Group A or B, plain or coated
  - F436 T3 – Group A or B for weathering applications

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Other Standards Used

- When to use other bolt grades
  - A449
  - A354
- Head dimensions, configuration or geometry
- Over 1-1/2” A490
- Thread length deviation
- Coatings

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What you should know about A354BD

- Dimensions not heavy hex unless you specify
- Consider specifying max tensile
- Consider Carb/Decarb testing
- Consider Magnetic Particle testing
- Be careful with thread length

- *From ASTM A354 "When bolts of Grade BD of this specification are considered for pretentioned applications in excess of 50 % of the bolt tensile strength, the additional requirements of head size, maximum tensile strength, nut size and strength, washer hardness, tests, and inspections contained in Specification A490 should be carefully considered."*

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COATINGS

Coatings on Structural Bolts

- B695 Zinc Mechanically Deposited – Group A Only
- F2329 Zinc Hot Dip – Group A except Twist-Off
- F1136 Zinc/Aluminum – Group A or B except Twist-Off
- F2833 Zinc Rich Base Coat and Aluminum Organic/Inorganic Type – Group A or B except Twist-Off
- F1941 Electrodeposited Coatings – Group A Hex Only

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Coatings on Structural Bolts

- Others possible for 120KSI Grades (Group A)
- Others coming for 150KSI Grades (Group B)
- Not always done by the manufacturer
- Significantly effect thread fit and “K” Factor

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Coatings on Structural Bolts

- Thickness only measured on significant surfaces
- Not typically corrosion tested on a lot by lot basis
- HDG on external threads only
- Thread oversizing tolerances for newer coatings on A490 fasteners have not been standardized yet

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Understanding Thread Fit - Coatings

- Nut threads need to be oversized for most coatings
- Oversizing the pitch diameter for clearance increases the nut minor diameter
- Oversized nuts have less proof load capacity
- Oversizing may change failure modes from bolt tensile failure to thread stripping
- Bolt tensile and nut proof load testing are performed with fixtures, results do not correlate to fastener assemblies
- Care should be taken not to “over-tension” coated fasteners
- Understand the specifics of your selected coating

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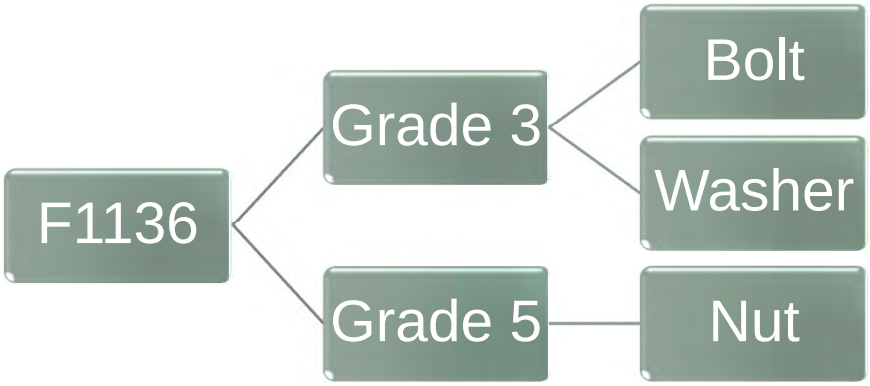
Coatings Example – Zinc Aluminum Flake



http://www.boltcouncil.org/files/F1136Bulletin.pdf

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Coatings Are Not Elastic

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JOBSITE REQUIREMENTS

See RCSC specification for details

Storage and Handling

Properly Stored

Properly Stored

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Storage and Handling

Not Properly Stored

Not Properly Handled

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Pre-installation Testing

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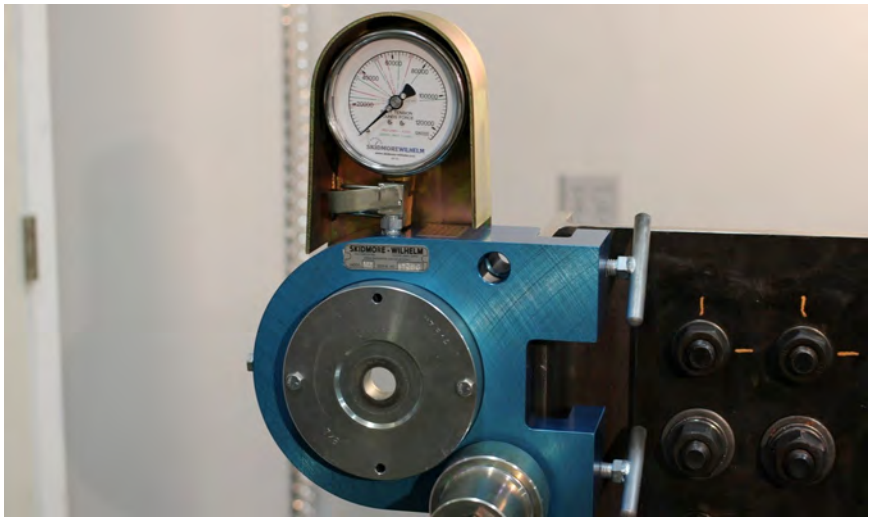
Tension Measuring Device



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Should Be Present When Bolt Tension is Required

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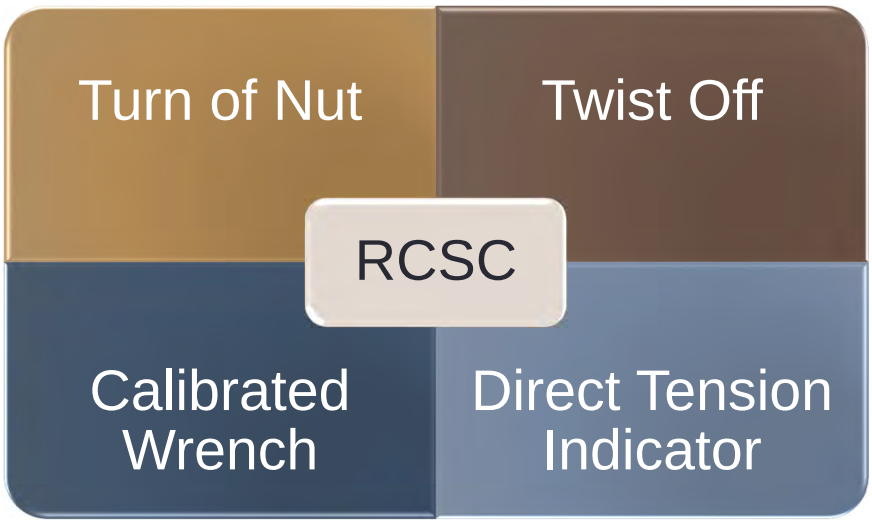
INSTALLATION METHODS

See RCSC specification for more details…

Installation Types – Tensioned or SC



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Snug Tight – What is it?

- All tensioning methods depend on achieving snug tight condition first.
- 2000 – 2004 Rev. RCSC Specification
  - "The snug-tightened condition is the tightness that is attained with a few impacts of an impact wrench or the full effort of an ironworker using an ordinary spud wrench to bring the plies into firm contact."
- 2009 Rev. RCSC Specification
  - "Snug tight is the condition that exists when all of the plies in a connection have been pulled into firm contact by the bolts in the joint and all of the bolts in the joint have been tightened sufficiently to prevent the removal of the nuts without the use of a wrench."

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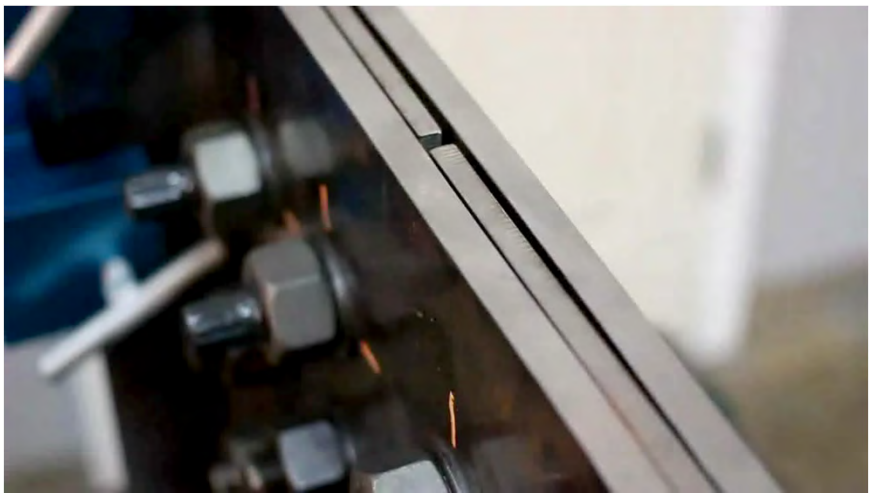
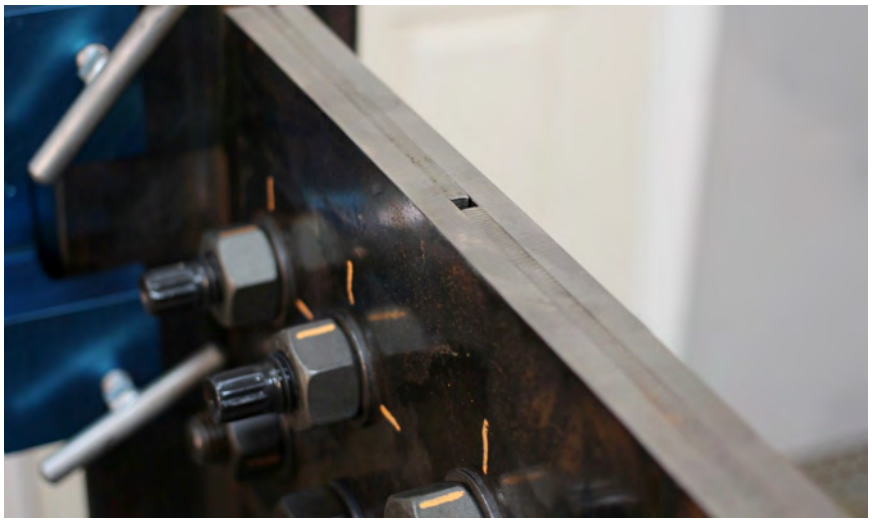
Snug Tight Process



93

Snug Complete



94

Heavy Hex Assembly

95

Heavy Hex Assembly

- Snug only
  - Shear/bearing connection
- Tensioned
  - Turn of Nut – tension by elongation
  - Calibrated Wrench – tension by calibrated torque
  - DTI (direct tension indicator) washer – tension by compression

96

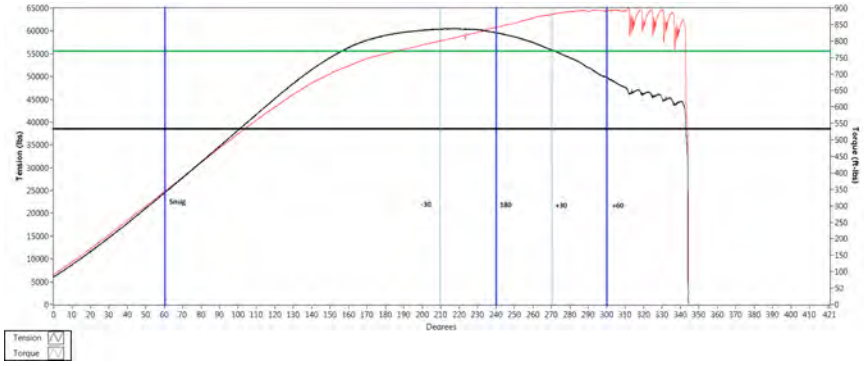
Non-impacting, Non-reacting Tools

Reaction arm to neighboring bolt

Reaction arm to steel or other

97

Turn of The Nut

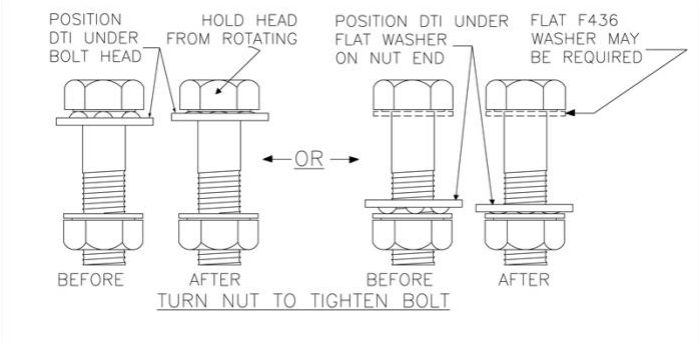


98

DTI Washer

99

DTI



100

Twist Off Bolts

101

Twist-Off Bolts

- Single side installation
- Visual indicator
- Calibrated torque

102

103

104

105

Single Side, Non-impacting, Non-reacting

Pneumatic

Electric

106

ROTATIONAL CAPACITY

Rotational Capacity Test

- Applicable to coated fasteners by ASTM
- Required on all assembly lots for bridge work

- Good, but extreme functional test of fasteners
  - What if connection only requires snug tight
  - Test generally tied to double the Turn of Nut installation requirement
  - Should be modified for Group B fasteners

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Rotational Capacity Test

ASTM

- Established by F16.02 for HDG bolts as a result of research that showed galvanized fasteners could not reliably reach minimum installation tension prior to torsional failure when HDG.
- Expanded to cover Mechanically Galvanized fasteners when B695 was added to A325.
- A means to test lubrication, which is required to prevent galling at the thread interface and bearing surface.
- Simple Pass/Fail test. You never know if you almost failed.
- Vague manufacturer requirement in A325, A325M and RCSC.
- End user confusion and difficult enforcement.
- Assuming bolt meets specification, test is primarily a function of nut (or coating) lubrication but is part of bolt specification
- Loosely based on the required degrees of turn for the Turn of Nut RCSC installation method, x2.

Primary criteria tested

- Thread fit (proper oversize to avoid interference fit)
- Mating thread strength (functional overlap) not using fixtures, considers zipper effect
- Lubrication (too little causes torsional failure)
- Bolt ductility (Extreme plastic performance or stretch beyond yield)

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Rotational Capacity Testing

AASHTO and FHWA, recognizing the benefits of the test, lubrication in particular, established a similar test, adding the requirement that the test be performed on ALL fasteners.

- Test is more involved
- Torque component
- Max torque permitted at minimum tension (via max K factor)
- Minimum tension at final rotation of 1.15 design tension
- This test is a good general bolt performance requirement
- These agencies primarily use bolts subject to high tension

Primary criteria tested

- Strength (tensile)
- Thread fit (proper oversize to avoid interference fit)
- Thread strength (functional overlap) not using fixtures, considers zipper effect
- Lubrication (too little causes torsional failure)
- Ductility (Extreme plastic performance or stretch beyond yield)

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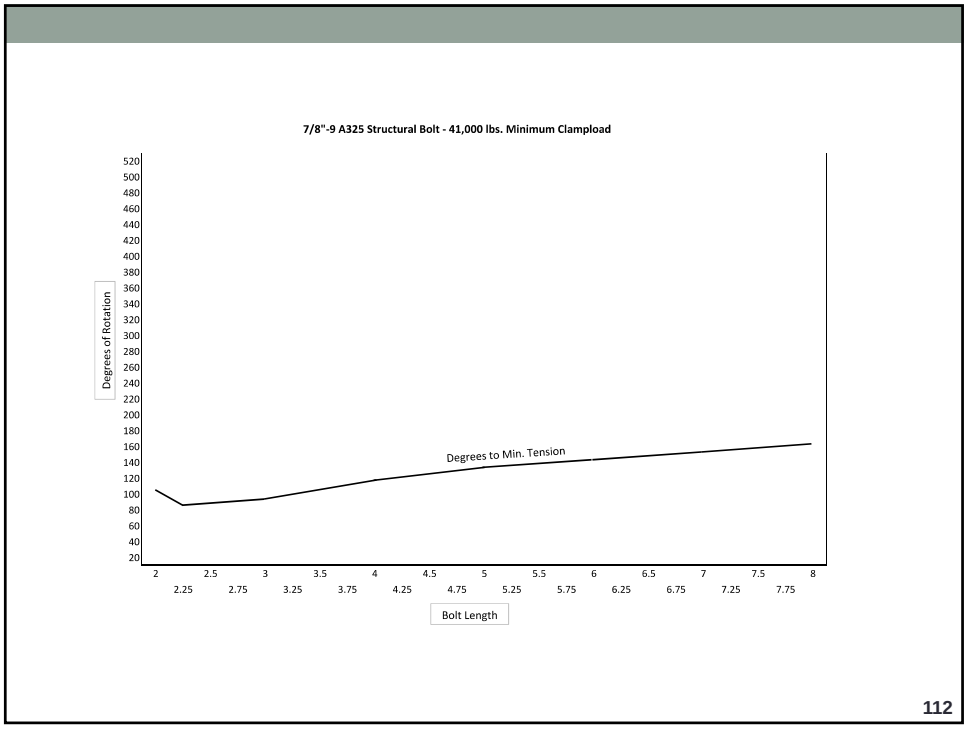
Rotational Capacity Testing

Problems with the current RC tests

- Required by ASTM at the manufacturer level, but should be at the distribution and end user level
- No way to place blame with the ASTM test. Hardware/Software dilemma
- ASTM does not address plain fasteners, which can have the same issues with lack of lubrication, particularly with Type 3 fasteners
- Nature of the test makes variability inevitable. Particularly number of washers, +/- angle tolerance, and number of threads in the grip
- Not all fastener assemblies need this level of performance by design
- “Coatings” often provide more lubricity than plain parts
- 3 different rotations for A325 inch, 5 different rotations for A325M
- A490 often held to same criteria as A325, but A490 is much less ductile
- AASHTO, FHWA cannot use ASTM test so they maintain their own version

111



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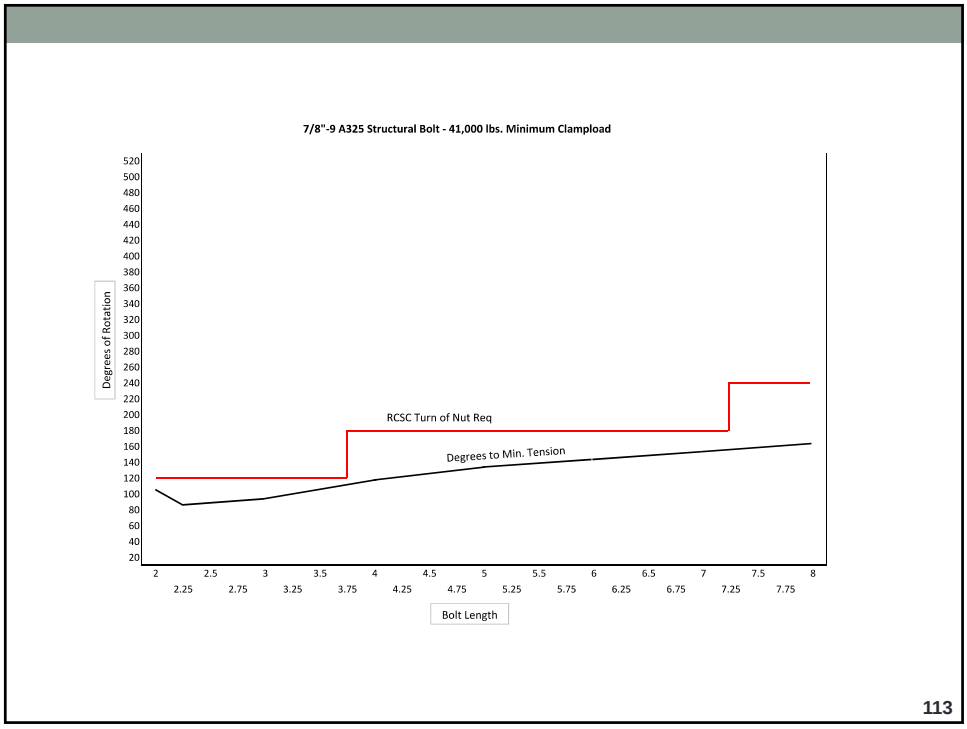

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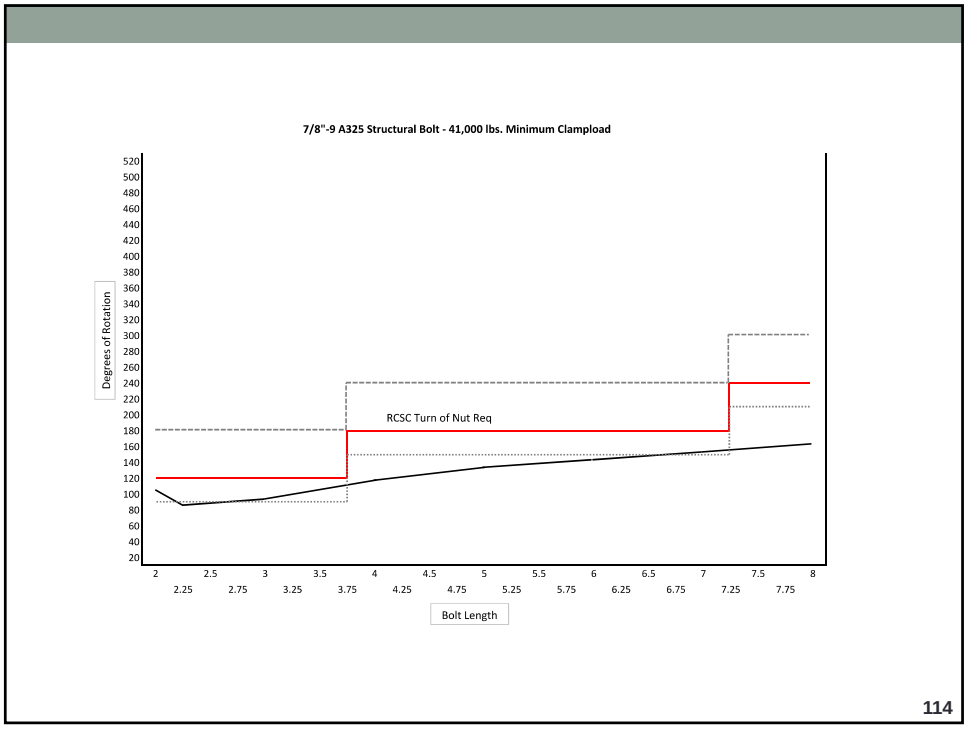

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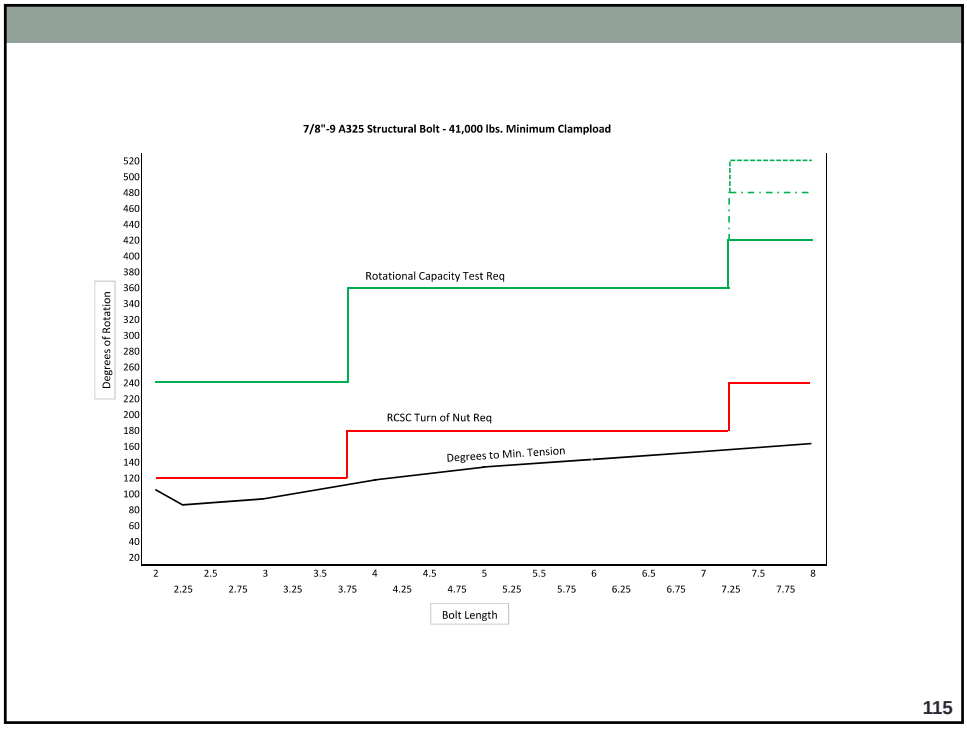

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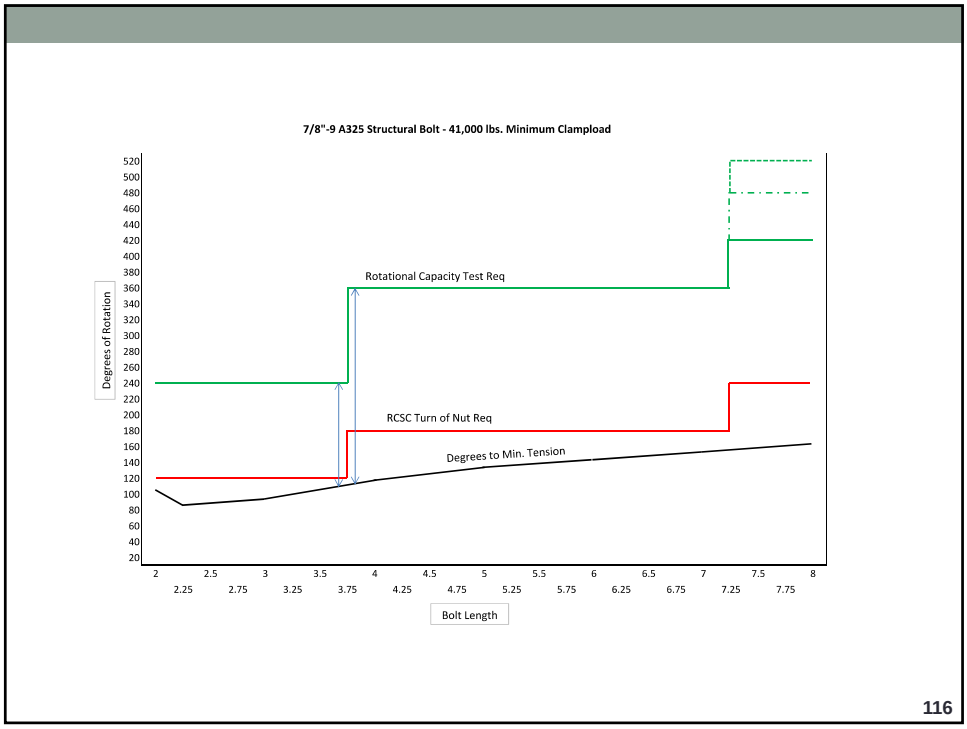

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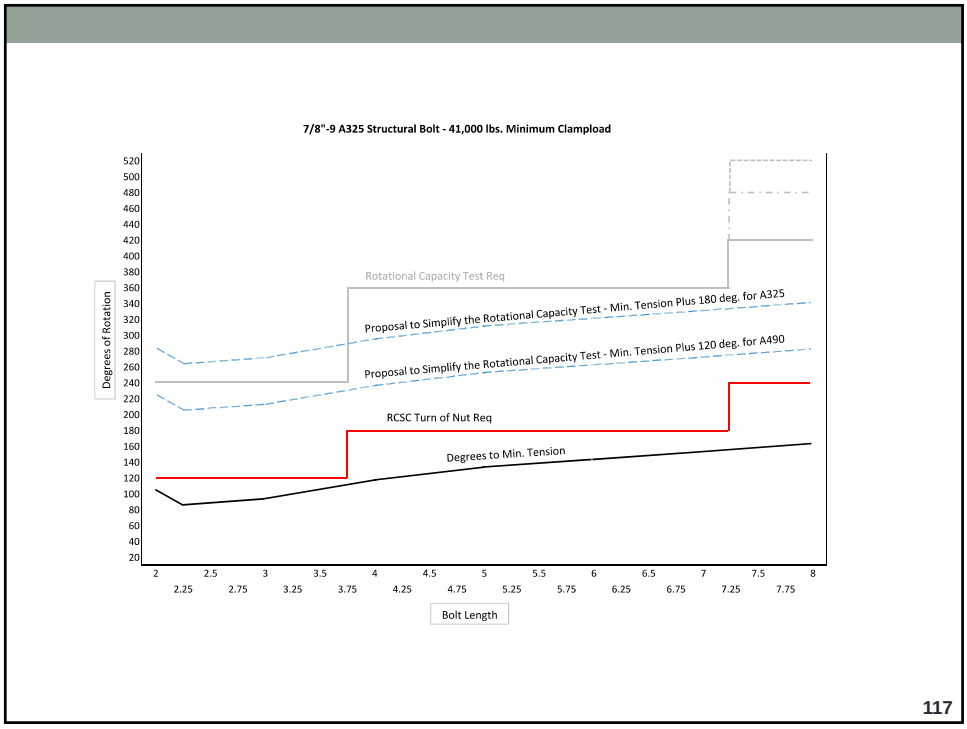

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GENERAL

Unusual Aspects of Structural Bolting

- Bolts are tensioned well into yield, this is a no-no in virtually every other engineered fastener application
- Bolts are not sold as matched sets in many cases
- Thread lengths are very short, bolts tend to perform better with longer threads
- Acceptance testing done in the field, which is often the 1st point of assembly
- There is no industry requirement for “K” Factor
- Snug tight as it pertains to fully tensioned bolts is highly variable

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PROBLEMS

Most projects go as planned, but……

What Can Happen?

- Fatigue
- Rust or Weathering
- Coating Adhesion
- Reamed Nut Threads
- White Rust
- Seams
- Bursts
- Poor Coating Thickness
- Welded Parts
- Storage and Handling Issues
- Quench Cracks
- Improper Washer Usage
- Bolt Binding
- Paint Adhesion
- No Pre-installation Testing
- Tensile Failure
- Torsional Failure
- Stress Corrosion Cracking
- Hydrogen Embrittlement
- Shank Out/Negative Stick-out
- Low Tension
- RC Test Failure
- Inadequate Installation Tools
- Lack of Installer Training
- High or Low Hardness
- Thread Stripping
- No Control of Snug Tight
- No Installation Clearance
- Improper Mating Components
- No Verification on Site

121

Surface Discontinuities

Burst

Seam

122

Bursts Are Quite Common

Head burst

Head burst

123

Burst, Seam or Crack?

Seam

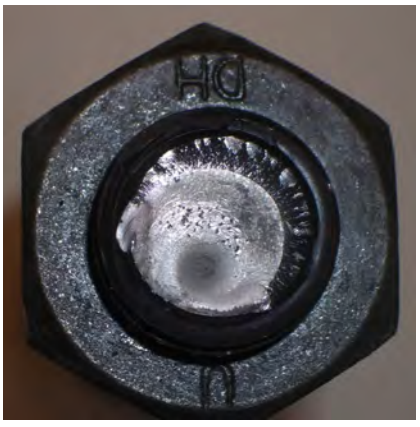
Quench crack

124

Call Somebody

Quench crack

Quench crack



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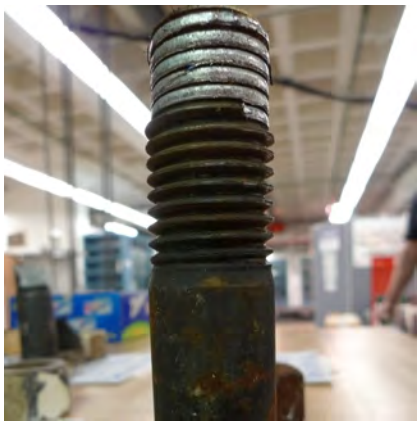
Other Problems

Bad threads or lack of engagement?



Adhesion or excessive impacting or bound bolt?

126

Too brittle?

127

Or Wrong Size?

128

Hot Forged, Split Die

Fin – in specification

Fin profile with a bit of swell

129

Misc. Problems

Coating Fixture Marks

Reamed Nut

130

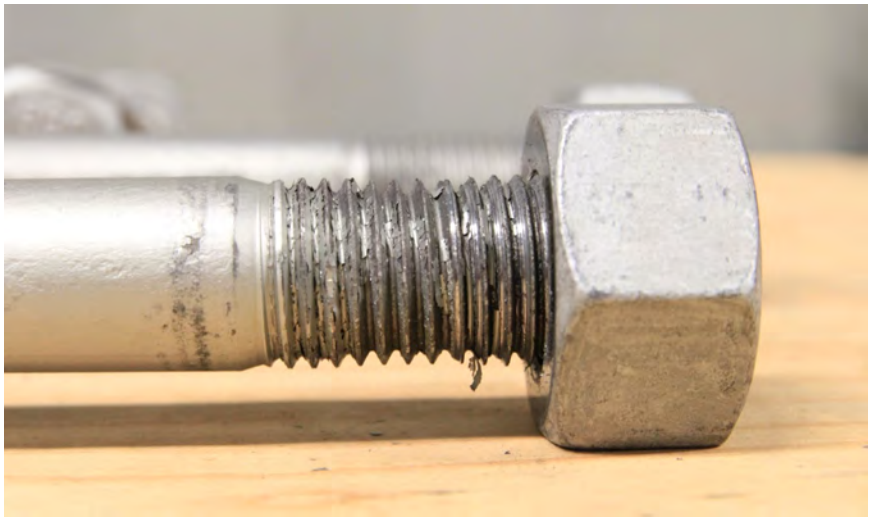
Workmanship

Bolt problem or hole problem?

Wow…

131

Unfortunately Very Typical



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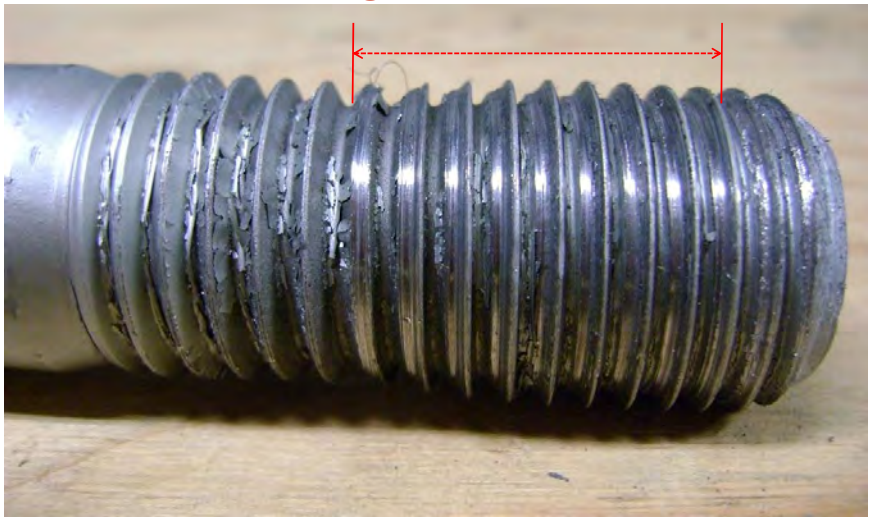
Trained Installer, Match-Marked, Witnessed, Signed-off, didn't break.

133

Trained Installer, Match-Marked, Witnessed, Signed-off, didn't break.



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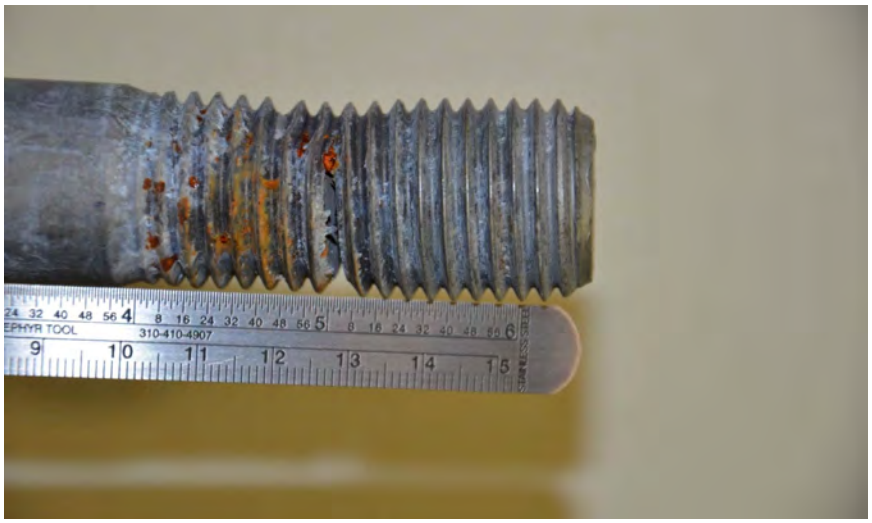
Same Connection Weeks Later



135

Rust - How Much is Too Much?

Might be OK, but need requalification

These are scrap

136

Good Reading

- John H. Bickford, An Introduction to the Design and Behavior of Bolted Joints. 3rd Edition.
- Industrial Fasteners Institute, Fastener Standards, 8th Edition. Industrial Fasteners Institute.
- Geoffrey L. Kulak, John W. Fisher, John H. A. Struik, Guide to Design Criteria for Bolted and Riveted Joints, second edition.
- Geoffrey L. Kulak, High Strength Bolts: A Primer for Structural Engineers, AISC.
- PCB Load & Torque Knowledge Library
  - Understanding Torque-Angle Signatures of Bolted Joints
  - Fundamentals of Torque-Tension and Coefficient of Friction Testing
  - Engineering Fundamentals of Threaded Fastener Design and Analysis

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What Else Can You Do?

- Get additional fastener training, a number of options exist
- Get more familiar with the standards
- Ask questions
- Get involved in committee work
- Work with reputable contractors and suppliers
- Be willing to work through problems

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Thank You

CEU Certificates

Within 1 business day…

- You will receive an email on how to report attendance from: steel@wyndhamjade.com
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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  Username: Your Attendee ID (found on your reg. receipt)
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Thank You

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