FASTENER FUNDAMENTALS

Chad Larson
Vice President
LeJeune Bolt Company

AISC Live Webinars

Thank you for joining us. The presentation will begin shortly. Please standby.
Today’s audio will be broadcast through the internet.

Alternatively, to hear the audio through the phone, dial 800 272 5460.

Today’s live webinar will begin shortly. Please standby.
As a reminder, all lines have been muted. Please type any questions or comments through the Chat feature on the left portion of your screen.

Today’s audio will be broadcast through the internet. Alternatively, to hear the audio through the phone, dial 800 272 5460.
AISC Live Webinars

AISC is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Copyright Materials

This presentation is protected by US and International Copyright laws. Reproduction, distribution, display and use of the presentation without written permission of AISC is prohibited.

© The American Institute of Steel Construction 2013
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.

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.
FASTENER FUNDAMENTALS

Chad Larson
Vice President
LeJeune Bolt Company

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
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

Forces on a Bolted Connection

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

---

**IT TAKES AN ARMY**
Bolted Connection

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

AISC

Bolted Connection

RCSC

ASTM
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”

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
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

HOW ARE BOLTS AND NUTS MADE?
Typical Cold Forming Progression

Cold Forming
Cold Forming Progression

Steel Coils (Typical) → Anneal (Depends) → Pickle and Coat

Quench and Temper Heat Treatment → Cold Form by Heading & Roll Threading → Draw Wire to Size

Plating or Coating if required → Inspection → Packaging

Cold Forming

- [http://youtu.be/3kxcw08p_oY](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
Bolt Hot Forging

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
Thread Rolling

How Are Nuts Made?
Hot Forming Progression

Steel in Bars → Hot Form Nut Blank → Descale (Sometimes) → Quench and Temper Heat Treat → Tapping → Plating or Coating if Required → Lubrication if Required → Inspection → Packaging

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

Understanding the Curve

Image courtesy of Fastenal
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
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

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?
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
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.

Understanding Threads
Basic Thread Terms

Pitch vs. Pitch Diameter (P.D.)

- Pitch is simply thread spacing
  - Inch series in TPI or 7/8"-9 x 2" is 9 Threads Per Inch
  - 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
**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

---

**Understanding Threads**

[Diagram showing internal and external thread profiles with key dimensions labeled.]
Understanding Thread PD

Gage Contact Profile for Pitch Diameter Size Measurements

Product External Thread

P.D. Vee Contact

P.D. Cone Contact

Thread Profile Standard Tap

Nut Thread

Bolt Thread
Thread Profile Over-Sized
Thread Profile Over-Sized

Single Point Measurement
Multi Point Measurement

Thread Class

Copyright © 2014
American Institute of Steel Construction
Thread Lengths – Not All Equal

Mating Components

Improperly mated

Improperly mated
SHEAR

Understanding Shear

Load

Load

Load

Load

Copyright © 2014
American Institute of Steel Construction
Understanding Shear

 Threads EXcluded

 Threads INcluded

 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

“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.

$$K = \frac{T}{N} \cdot \frac{12}{D}$$

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

Example: $\frac{3}{4}'' \times 2''$ TC Bolt. 300 ft. lbs. torque at 35,000 lbs. clamp load.

$$K = \frac{300}{35000} \cdot \frac{12}{.750} = .137$$

Solving for Torque the equation becomes $T = KDN/12$
Lubrication

Lubrication or Coating “K” Factor

Copyright © 2014
American Institute of Steel Construction
Lubrication

Paint adhesion

Lubrication

Copyright © 2014
American Institute of Steel Construction
STRUCTURAL BOLTS

Structural Bolt Grades

120 KSI Min Tensile – “Group A”
- A325
- A325M
- F1852

150 KSI Min Tensile – “Group B”
- A490
- A490M
- F2280

Copyright © 2014
American Institute of Steel Construction
Structural Bolt Types

- **Type 1 Carbon Steel**
  - A325 Group A
  - A325M Group A
  - F1852 Group A
  - A490 Group B
  - A490M Group B
  - F2280 Group B

- **Type 3 Weathering Steel**
  - A325 Group A
  - A325M Group A
  - F1852 Group A
  - A490 Group B
  - A490M Group B
  - F2280 Group B

Structural Bolt Styles

- **Heavy Hex Head**
  - A325 Group A
  - A325M Group A
  - A490 Group B
  - A490M Group B

- **Twist-Off**
  - F1852 Group A
  - F2280 Group B
Structural Bolts

Strength

Ductility

Structural Bolts

150 KSI Group B

120 KSI Group A

Availability
Ductility
Coatings
Less Risk

Strength
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

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
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.”*
## 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

### Others possible

- 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
## 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

---

## 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
Coatings Example – Zinc Aluminum Flake

F1136
Grade 3
Bolt
Grade 5
Washer
Nut


Coatings Are Not Elastic
JOBSITE REQUIREMENTS
See RCSC specification for details

Storage and Handling

Properly Stored

Properly Stored
Storage and Handling

Not Properly Stored

Not Properly Handled

Pre-installation Testing
Tension Measuring Device

Should Be Present When Bolt Tension is Required
INSTALLATION METHODS

See RCSC specification for more details…

Installation Types – Tensioned or SC

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

RCSC 90
Snug Tight – What is it?

- All tensioning methods depend on achieving snug tight condition first.

  - “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.”

Snug Tight Process
Snug Complete

Heavy Hex Assembly
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

Non-impacting, Non-reacting Tools

Reaction arm to neighboring bolt

Reaction arm to steel or other
Turn of The Nut

DTI Washer
DTI

Twist Off Bolts
Twist-Off Bolts

- Single side installation
- Visual indicator
- Calibrated torque
Single Side, Non-impacting, Non-reacting

Pneumatic

Electric

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

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)
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)

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
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
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
Surface Discontinuities

Burst

Seam

Bursts Are Quite Common

Head burst

Head burst
Burst, Seam or Crack?

Seam

Quench crack

Call Somebody

Quench crack

Quench crack
Other Problems

Bad threads or lack of engagement?

Adhesion or excessive impacting or bound bolt?

Too brittle?
Or Wrong Size?

- Hot Forged, Split Die
  - Fin – in specification
  - Fin profile with a bit of swell
Misc. Problems

Coating Fixture Marks

Reamed Nut

Workmanship

Bolt problem or hole problem?

Wow…
Unfortunately Very Typical

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

Same Connection Weeks Later
Rust - How Much is Too Much?

Might be OK, but need requalification

These are scrap

Good Reading

- 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
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

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!

OR…

There’s always a solution in steel

CEU Certificates

Access available in 24 hours…

• Go to:
  http://www.wynjade.com/aisc14/webinarceu
  Username: Your Attendee ID (found on your reg. receipt)
  Password: Your Last Name

• Completely fill out online form. Don’t forget to check the boxes next to each attendee’s name!
• Questions? Please email us at webinars@aisc.org.

There’s always a solution in steel
AISC Webinars

February 13, 2014:
Design of Reinforcement for Steel Members Part II
Presented by Bo Dowswell, Arc International

www.aisc.org/webinars

AISC Seminars

Spring 2014 Schedule has been released!
24 cities this spring

www.aisc.org/seminars
AISC Night School

Fundamentals of Earthquake Engineering for Building Structures
Presented by Rafael Sabelli, Walter P Moore

Class begins February 24, 2014!

www.aisc.org/nightschool

Thank You

Please fill out a brief survey at the conclusion of the webinar. Your feedback is greatly appreciated.