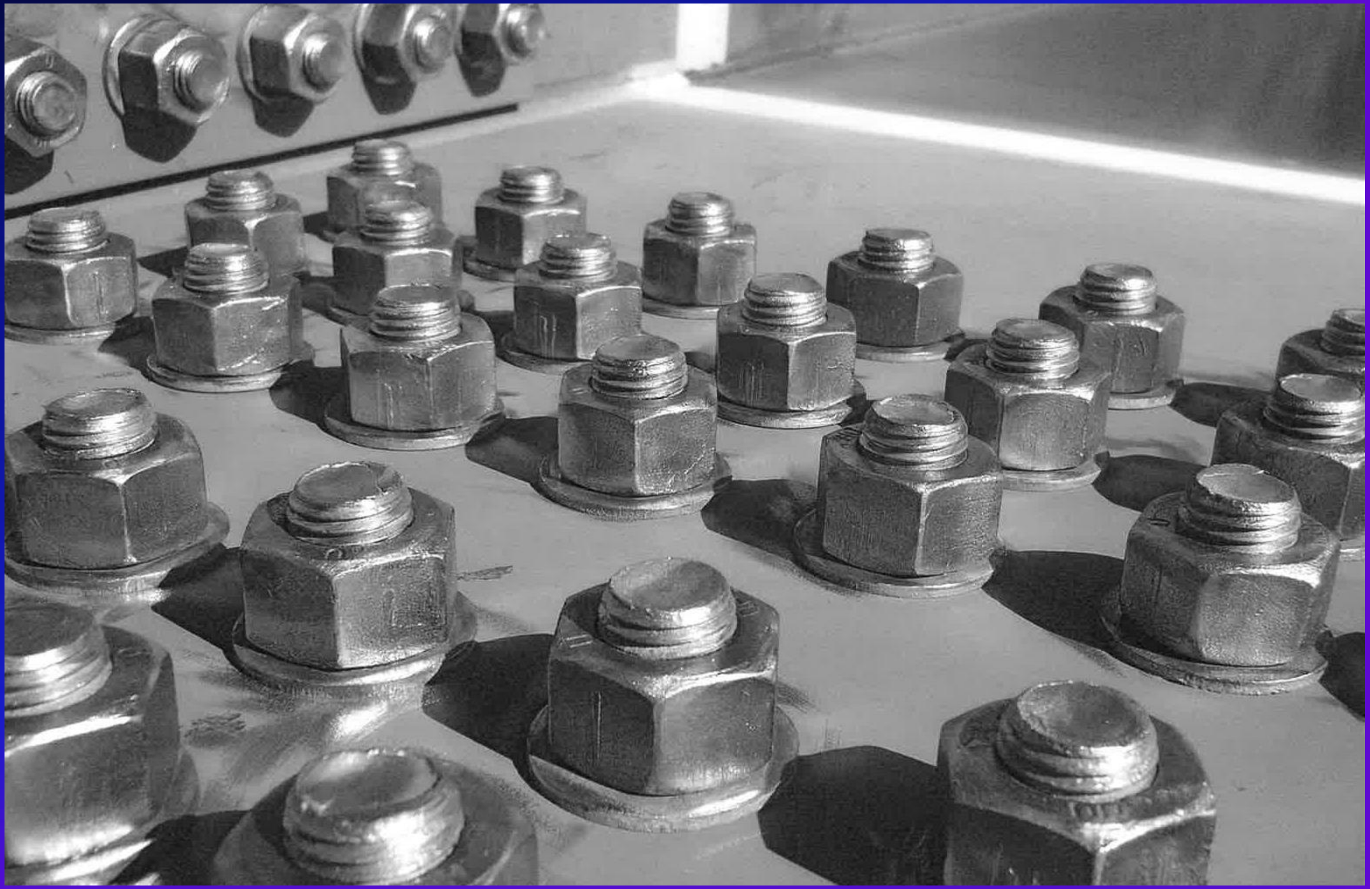
Unravelling the Confusion Surrounding the Painting of Bolted Connections



Kenneth A. Trimber
KTA-Tator, Inc.

KTA
Quality and Integrity Since 1949

Bolted Connection Webinar Learning Objectives

- Understand the coefficient of friction and tension creep testing used to certify coatings for slip-critical bolted connections
- Recognize the challenges associated with using coatings in slip-critical bolted connections
- Recognize common approaches for addressing bolt holes (to paint or not to paint)
- Identify approaches to cleaning and painting galvanized and black fasteners

Agenda

- Slip Coefficient and Tension Creep Testing Processes
- Slip Classification and Discussion of Test Results
- Painting of Bolt Holes
- Cleaning and Painting of Fasteners

RCSC Specification

- Research Council on Structural Connections (RCSC)
- Specification for Structural Joints Using High-Strength Bolts, August 1, 2014 (with April 2015 errata)
- Currently under review

Specification for Structural Joints Using High-Strength Bolts

August 1, 2014
(includes April 2015 Errata)

Supersedes the December 31, 2009 *Specification for Structural Joints Using High-Strength Bolts*.

Prepared by RCSC Committee A.1—Specifications and approved by the Research Council on Structural Connections.

boltcouncil
rcsc

www.boltcouncil.org
RESEARCH COUNCIL ON STRUCTURAL CONNECTIONS
c/o AISC, One East Wacker Drive, Suite 700, Chicago, Illinois 60601

COF and Tension Creep Testing

- Coefficient of Friction (COF) Testing
  - Determines the mean slip coefficient of a coating applied to the faying surfaces of bolted connections under short-term static loading – each test run ~7 min
- Tension Creep Testing
  - Tendency of a coating to undergo deformation under sustained service loading – 1,000 hrs (42 days)
  - Includes the effect of a loss in clamping force due to compression or creep deformation of the coating
- Specimens must pass COF testing before being subjected to Tension Creep testing

RCSC Certification Classes

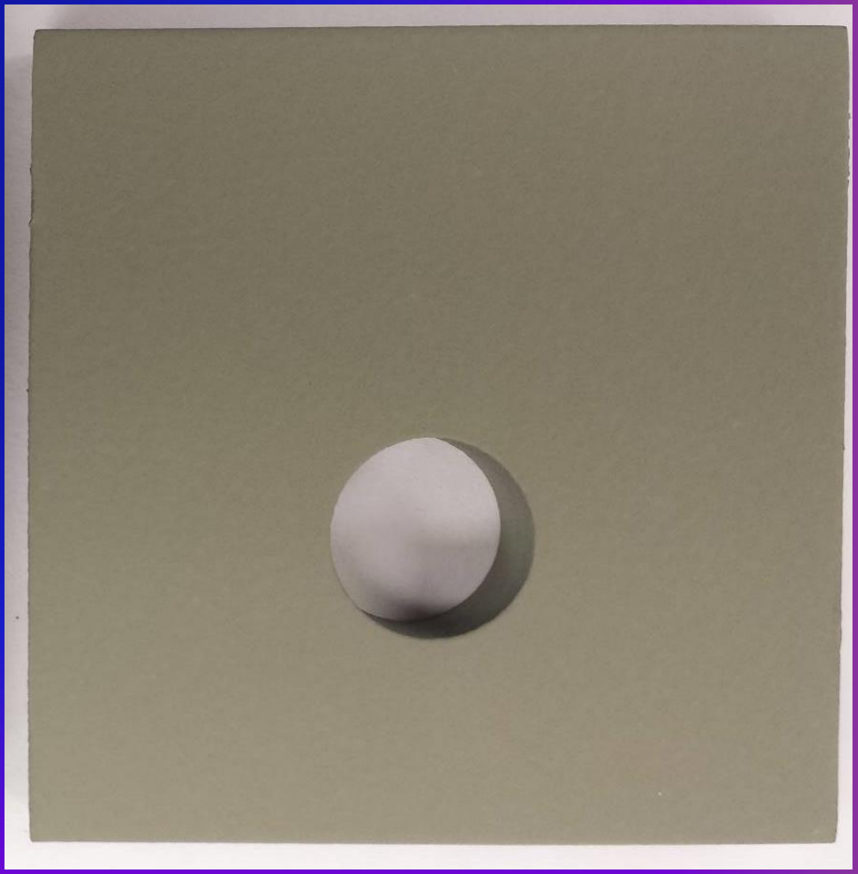
- Class A Certification
  - minimum slip coefficient of 0.30
- Class B Certification
  - minimum slip coefficient of 0.50
- Class C Certification
  - minimum slip coefficient of 0.35

Test Plates for COF

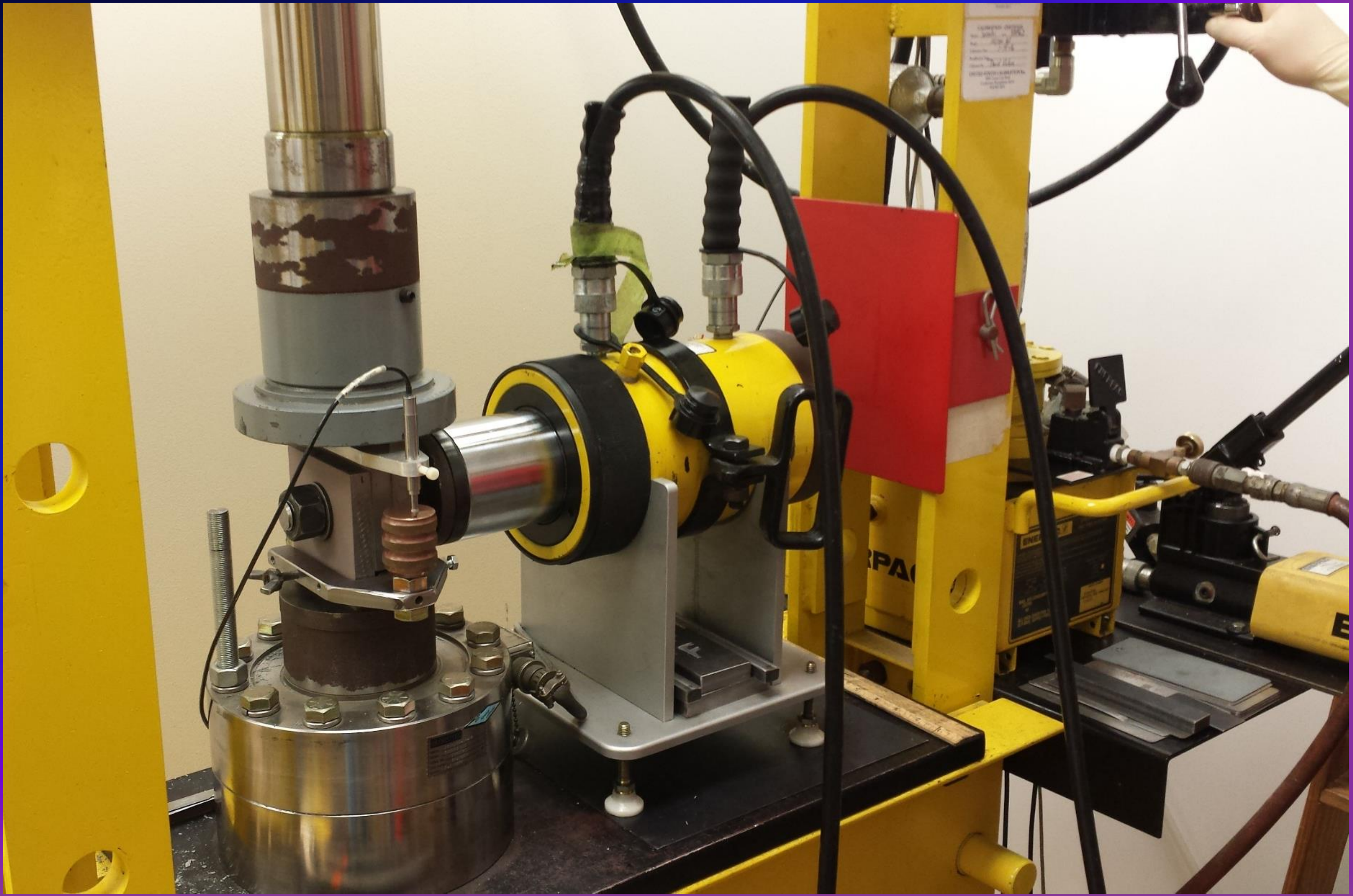
- Flat carbon steel (no raised edges, protruding defects or warp) – typically cold rolled to achieve greater flatness
- 5/8″ x 4″ x 4″ with a 1″ hole drilled 1 ½″ from one of the sides
- One ⅝″ x 4″ edge (top edge in the photo) is machined smooth

Test Plates for COF (con't)

- Each plate is abrasive blast cleaned and both sides are coated with the test material
- Thickness is 2 mils greater than the maximum that will be applied to the joint (typically 2 mils greater than the manufacturer's recommended maximum)
- Certification does not include the extra 2 mils
- 3 plates are sandwiched together for each test

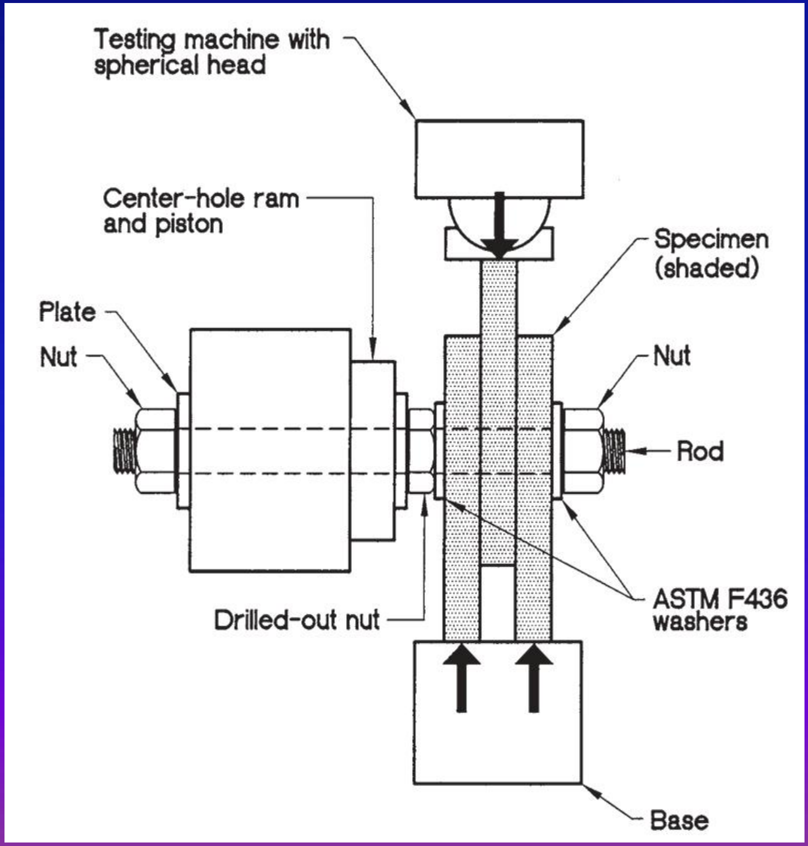


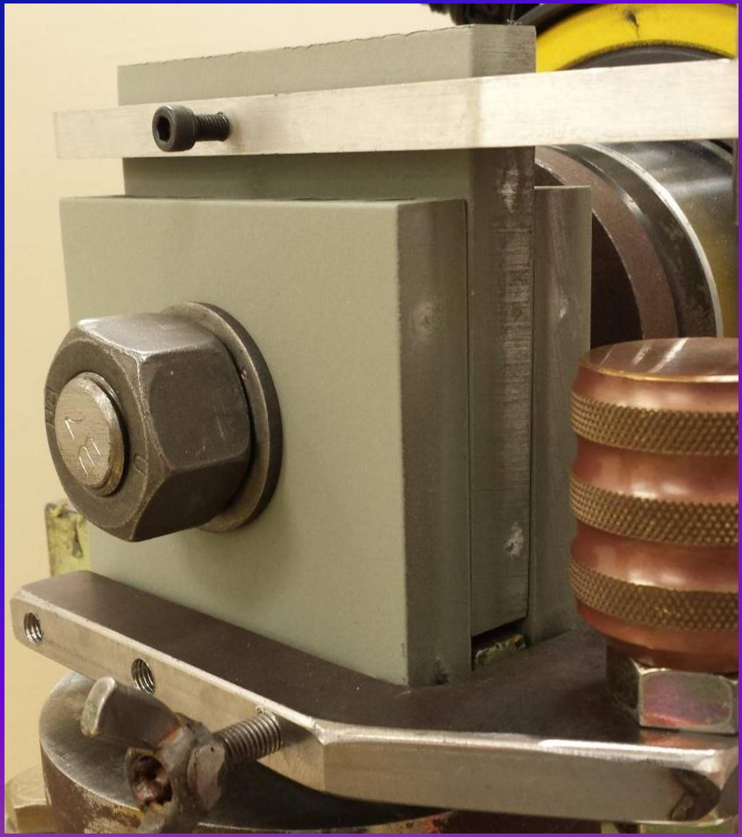
COF Testing



COF Testing (con't)

- Threaded rod, not bolt, inserted is through the plates – secured with nut
- Clamping force applied using a hydraulic cylinder
  49 ± 0.5 kips (based on min. clamping force of A490 bolt)





COF Testing (con't)

- Vertical load applied to the center plate until slip occurs – rate not to exceed 25 kips/min
- Each test ~7minutes
- Testing performed on 5 replicates (15 test plates total)

Test Plates for Tension Creep

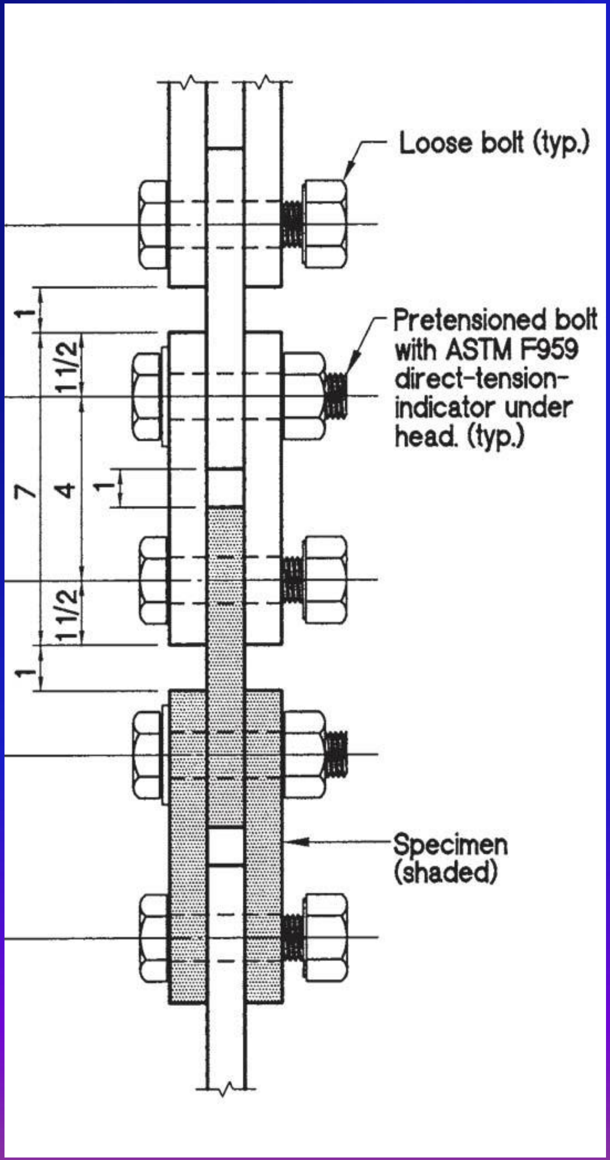
- Flat carbon steel (no raised edges, protruding defects or warp) – typically cold rolled to achieve greater flatness
- 5/8″ x 4″ x 7″ with a 1″ hole drilled 1 ½″ from both of the 4″ sides

Test Plates for Tension Creep (con't)

- The degree of blast cleaning and DFT of the test material is the same as the COF plates
- Only ½ of each plate is coated on both sides – the remaining half is left as bare blast cleaned steel

Test Plates for Tension Creep (con't)

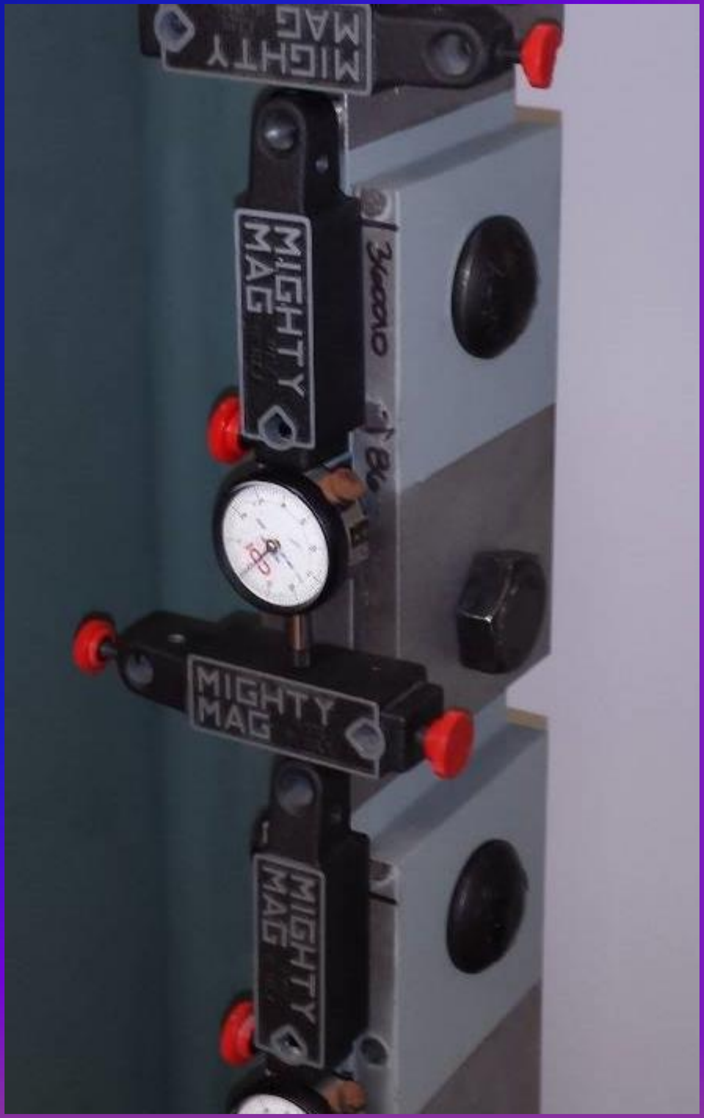
- 9 plates are required for each test
- 3 sets of 3 replicates assembled in a chain
- Painted surfaces are matched to painted surfaces; unpainted matched to unpainted
- Only one chain is required for each test



Tension Creep Testing

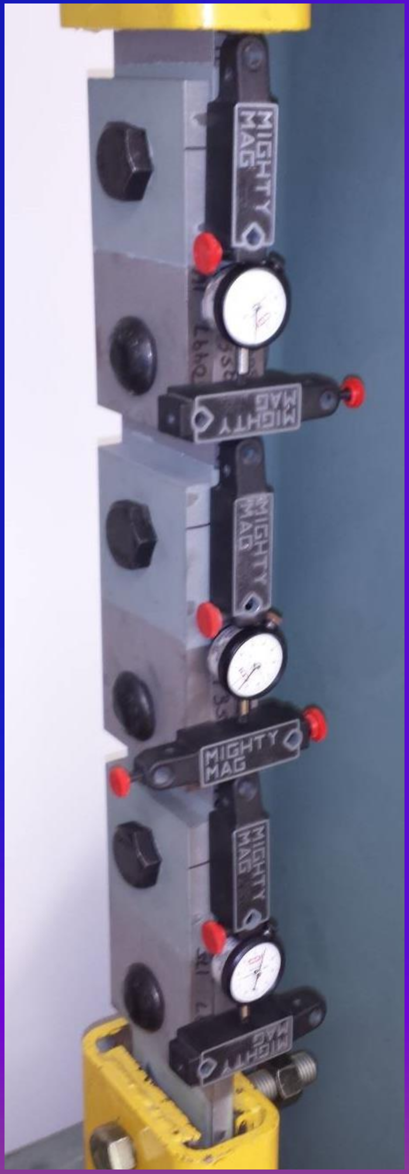
Tension Creep Testing (con't)

- Painted surfaces secured with 7/8"diameter A490 bolts
- Unpainted surfaces are connected using loose pin bolts and are not part of the test (in bearing)



Tension Creep Testing (con't)

- A load is applied to the chain in tension and held for 1,000 hours (approximately 42 days)
- After 1,000 hours, the tension is increased over the course of a few minutes to the final load
- The loads are calculated from formulas based on the targeted slip coefficient classification and the average clamping force of the samples.
- For Class B, the locked tension (1,000 hours) is a minimum of 32.7 kips and a minimum of 49 kips for final tension



Tension Creep Testing (con't)

- Movement of the center plates is monitored relative to the outside plates in tenths of a mil.
- Creep deformation >5mils for any sample during the 1,000 locked tension is a failure for the slip coefficient used
- If deformation of each sample after 1,000 hours is <5 mils, testing proceeds to the final tension.
- The average deformation after final tension must be <15 mils for the three specimens

Discussion - Slip Coefficient/ Tension Creep Classes

- Class A Certification (minimum slip COF 0.30)
  - clean mill scale typically meets Class A
- Class B Certification (minimum slip COF 0.50)
  - bare abrasive blast cleaned steel, most inorganic zinc primers, and some organic zinc primers typically meet Class B
- Class C Certification (minimum slip COF 0.35)
  - roughened galvanizing typically meets Class C

Discussion - Thermal Spray Coatings (TSC)

- FHWA study (Slip and Creep of Thermal Spray Coatings, Publication No. FHWA-HRT-14-083) September, 2014
  - Tested sealed and unsealed 100% zinc and 85/15 (zinc/ aluminum)
- Unsealed TSC
  - slip coefficient >0.75
  - meets Class B
- Sealed TSC
  - slip coefficient 0.41 (zinc) and 0.44 (85/15)
  - does not meet Class B

TECHBRIEF

Slip and Creep of Thermal Spray Coatings

Publication No. FHWA-HRT-14-083

FHWA Contact: Justin Ocel, HRDI-40, (202) 493-3080, justin.ocel@dot.gov

Introduction

All steel bridge systems and their components need some level of corrosion protection to assure a serviceable life. One of two approaches is typically used: either the bridge component is fabricated from a corrosion-resistant alloy, or the steel is coated for protection. The most common coating practice is use of a multilayered paint system over a zinc-rich primer. Other coating alternatives for corrosion protection are hot-dip zinc galvanization and thermal spray coatings (TSC). Both galvanization and TSCs offer better long-term corrosion protection than zinc-bearing paint systems in severe environments. For this reason, these alternative-coating systems need to be mainstreamed for the protection of steel bridges.

In addition to corrosion resistance, the coating must be compatible with use in high-strength bolted connections. The *American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications* require bolted connections be designed as "slip-critical" if the connection is subjected to "…stress reversal, heavy impact loads, severe vibration or located where stress and strain due to joint slippage would be detrimental to the serviceability of the structure…"[1] Slip-critical connections rely on the clamping force from the bolts to develop frictional shear stresses as the means to transfer force from one element to the next. This construction is in contrast to bearing connections, in which the individual connection elements bear on the bolt and the force is transferred through shear stresses in the bolt itself. In the design of a slip-critical connection, the engineer must select a "frictional slip coefficient" between the layers of a connection to calculate the slip resistance. AASHTO refers to this frictional value as a "surface condition factor," although in this TechBrief, it will be referred to as the "slip coefficient." The engineer does not specify an exact slip coefficient; rather, the *AASHTO LRFD Bridge Design Specifications* provide three different categories (Class A, B, and C) from which the engineer can choose.

Class A surfaces have a minimum slip coefficient of 0.33, which can be achieved with unpainted, clean mill scale. Class B surfaces have a minimum slip coefficient of 0.50, which can be achieved with unpainted, blast-cleaned surfaces. In lieu of having bare steel on the slip surface, certified coatings applied over a blast-cleaned surface that demonstrates Class A or B performance may also be used. Class C surfaces also have a minimum slip coefficient of 0.33 but are only applicable for hot-dip galvanized coatings and are outside the scope of this TechBrief.

U.S. Department of Transportation
Federal Highway Administration
Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296
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Discussion – Certificate of Testing

- Certification
  - The certificate is based on a specific product, dry film thickness, thinner amount, and curing time
  - The same product is applied to both faying surfaces
  - Specifications often require a different primer thickness in the joints compared to the remainder of the structure to comply with the maximum DFT on the certification

KTA

CERTIFICATE OF TESTING

This Certificate of Testing signifies that

Manufactured by

has been tested by KTA-Tator, Inc. in accordance with the Research Council on Structural Connections (RCSC) Specification for Structural Joints Using High-Strength Bolts (December 31, 2009), Appendix A and KTA SOP TL2523 for:

SLIP COEFFICIENT AND RESISTANCE TO TENSION CREEP

And meets the requirements of Class B under the following conditions:

Batch No. Tested: *Part A: XM0364PN; Part B: XM2533WN; Part F: 2733CL*

Minimum Cure Time: *7 Days at 22 ± 1°C and 50 ± 5% RH*

Maximum Dry Film Thickness: *5 mils*

Thinner Type: *None*

Maximum Thinner Addition: *None*

Test Period: *February 2014 – April 2014*

Slip Coefficient Value: *0.513*

Carly M. McGee
Physical Test Laboratory Supervisor

William D. Corbett, Vice President
Manager - Professional Services Group

KTA-TATOR, INC. 115 TECHNOLOGY DRIVE PITTSBURGH, PENNSYLVANIA 15275

Discussion - Coating Curing Times

- The test material is cured according to the manufacturer's requirements prior to assembly and testing
- The RCSC specification states that research has indicated "that all curing effectively ceased at the time the joint was assembled and paint that was not fully cured at that time acted as a lubricant. The slip resistance of a joint that was assembled after a time less than the curing time used in the qualifying tests was severely reduced. Thus, the curing time prior to mating the faying surfaces is an essential parameter to be specified and controlled during construction."

When the *faying surfaces* of a *slip-critical joint* are to be protected against corrosion, a qualified coating must be used. A qualified coating is one that has been tested in accordance with Appendix A, the sole basis for qualification of any coating to be used in conjunction with this Specification. Coatings can be qualified as follows:

(1) As a Class A coating as defined in Section 5.4;
(2) As a Class B coating as defined in Section 5.4; or,
(3) As a coating with a *mean slip coefficient* μ of 0.30 (Class A) but not greater than 0.50 (Class B).

Requalification is required if any essential variable associated with surface preparation, paint manufacture, application method or curing requirements is changed. See Appendix A.

For slip-critical joints, coating testing as prescribed in Appendix A includes creep tests, which incorporate relaxation in the fastener and the effect of the coating itself. Users should verify the coating thicknesses used in the Appendix A testing and ensure that the actual coating thickness does not exceed that tested. See Appendix A, Commentary to Section A3.

Frank and Yura (1981) also investigated the effect of varying the time between coating the *faying surfaces* and assembly of the *joint* and pretensioning the bolts in order to ascertain if partially cured paint continued to cure within the assembled *joint* over a period of time. The results indicated that all curing effectively ceased at the time the *joint* was assembled and paint that was not fully cured at that time acted as a lubricant. The slip resistance of a *joint* that was assembled after a time less than the curing time used in the qualifying tests was severely reduced. Thus, the curing time prior to mating the *faying surfaces* is an essential parameter to be specified and controlled during construction.

The *mean slip coefficient* for clean hot-dip galvanized surfaces is on the order of 0.19 as compared with a factor of about 0.33 for clean mill scale. Birkemoe and Herrschaft (1970) showed that this *mean slip coefficient* can be significantly improved by treatments such as hand wire brushing or light "brush-off" grit blasting. In either case, the treatment must be controlled to achieve visible roughening or scoring. Power wire brushing is unsatisfactory because it may polish rather than roughen the surface, or remove the coating.

Field experience and test results have indicated that galvanized assemblies may continue to slip under sustained loading (Kulak et al., 1987; pp. 198-208). Tests of hot-dip galvanized *joints* subjected to sustained loading show a creep-type behavior that was not observed in short-duration or fatigue-type load application. See also the Commentary to Appendix A.

3.3. Bolt Holes

The nominal dimensions of standard, oversized, short-slotted and long-slotted holes for *high-strength bolts* shall be equal to or less than those shown in Table 3.1. Holes larger than those shown in Table 3.1 are permitted when specified or

Discussion – Joining 2 Certified Coatings

- If two different brands of the same generic type (e.g., inorganic zinc) have their own Class B certifications, it can not be assumed that the two together will meet Class B
- If two different brands of a different generic type (e.g., inorganic zinc and organic zinc) have their own Class B certifications, it can not be assumed that the two together will meet Class B
- The specific combination of the coatings that will be used should be tested to be certified

Discussion – Coatings Beneath Bolt Head and Washer/Nut

- Compression of the coating beneath the bolt head and washer/nut could effect the bolt pretension for tension creep testing since the clamping force is accomplished using 7/8" A490 bolts

Discussion – Coatings Beneath Bolt Head and Washer/Nut (con't)

- Compression will not effect slip coefficient testing because the clamping force is maintained continuously during the test using a hydraulic cylinder

Discussion – Coatings Beneath Bolt Head and Washer/Nut (con't)

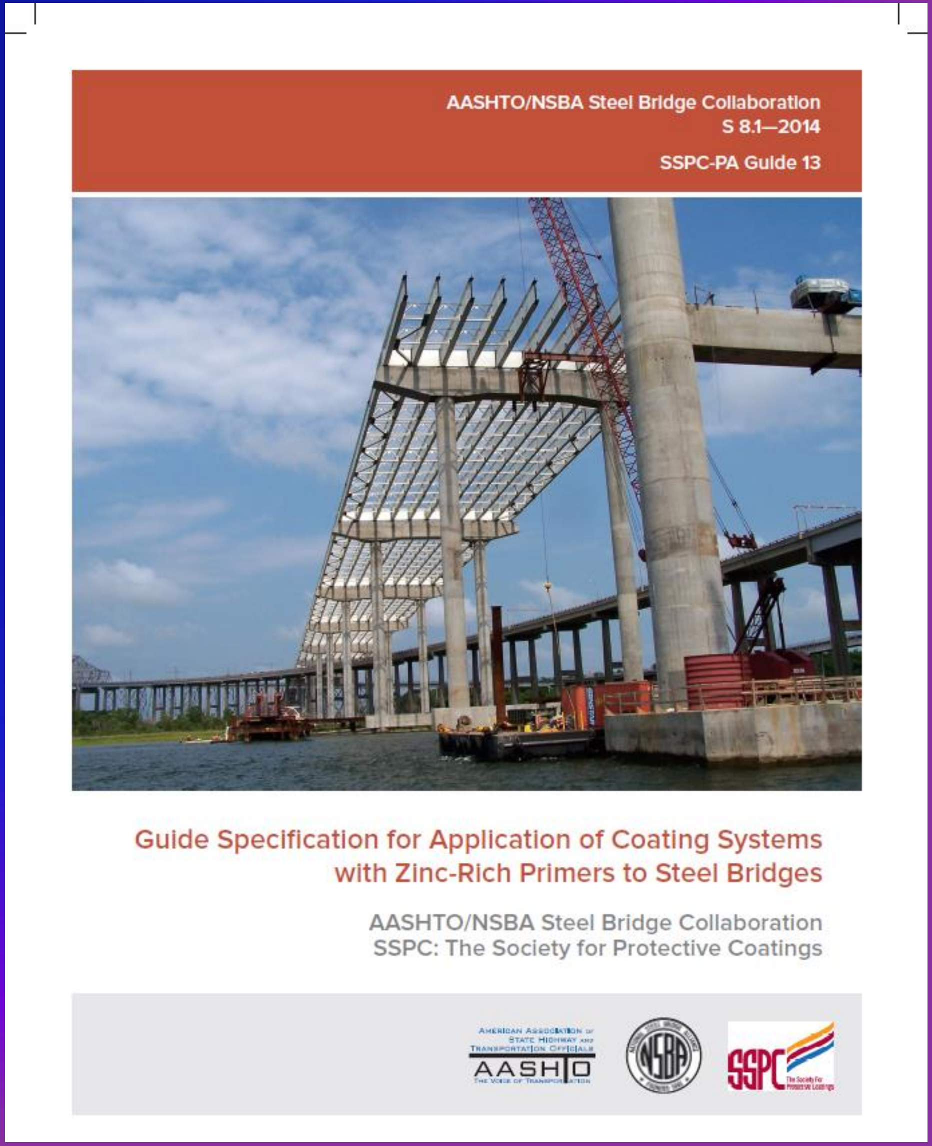
- Compression of the primer is taken into account in the tension creep testing since primer is applied to the backsides
- Application of additional coats on the backside (beneath the bolt head and washer/nut) is not taken into account unless specifically tested that way
- Professionals associated with the RCSC specification have stated that plates with 10 mils of coating on the backside (and beneath the bolt head and washer/nut) have been successfully tested in the past, and assume that 15 mils would be acceptable
- However, because of the many different coating types being used, if there is interest in applying all coats to the back sides of splice plates in the shop, consideration should be given to testing the specific products, especially if Class B certification is required

Painting of Bolt Holes

- The is no universal agreement on whether or not bolt holes should be painted
- Corrosion in bolt holes does not effect the life of the structure – once fasteners are in place, weather is sealed out
- Corrosion in bolt holes can lead rust staining on surrounding surfaces prior to erection

Painting of Bolt Holes (con’t)

- AASHTO/NSBA “Steel Bridge Collaboration S 8.1-2014,” is published as SSPC-PA Guide 13, “Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges.”



Painting of Bolt Holes (con't)

- 3.4 "Miscellaneous Surfaces to be painted and the coating system to be used shall be as indicated on plans and/or contract documents. Unless otherwise noted, paint is not required on flange surfaces that will be embedded in concrete, or inside bolt holes, although overspray is permitted on flange surfaces and inside bolt holes."

Painting of Bolt Holes (con't)

- SSPC-PA 1, "Shop, Field, and Maintenance Painting of Steel," is under revision
- A portion of the proposed revision to paragraph 7.8.1 states, "The application to, or removal of, coating from bolt hole interiors is not required unless specified in procurement documents, although overspray coating is frequently present."
- The project specification will dictate how bolt holes are to be treated, but is common to see them incidentally painted with overspray, rather than fully coated

Cleaning and Painting of Fasteners Black Bolts

- SSPC-PA Guide 13 "Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges" addresses the painting of black bolts and galvanized bolts in sections 5.5 and 5.5
  - When the bolts are installed prior to cleaning and painting the steel, the steel and fasteners are blast cleaned and painted at the same time
  - When installed after the steel is painted, the fasteners should be blast cleaned in place and painted
-

Cleaning and Painting of Fasteners Black Bolts (con't)

- There is substantial risk associated with blast cleaning fasteners installed in painted steel
- To clean all surfaces and threads, the nozzle has to be held at many angles and directions – there is potential for significant overblast damage of the surrounding coating
- Overblast damage may not be visible, escaping repair

Cleaning and Painting of Fasteners Black Bolts (con't)

- Large areas surrounding the fasteners have to be cleaned and painted, which becomes more complicated as more shop coats are applied
  - Feathering
  - Number of coats
  - Squaring up

Cleaning and Painting of Fasteners Black Bolts (con't)

- Consideration should be given to replacing black bolts with treated or galvanized bolts to eliminate the need for blast cleaning

Cleaning and Painting of Fasteners
Galvanized Bolts

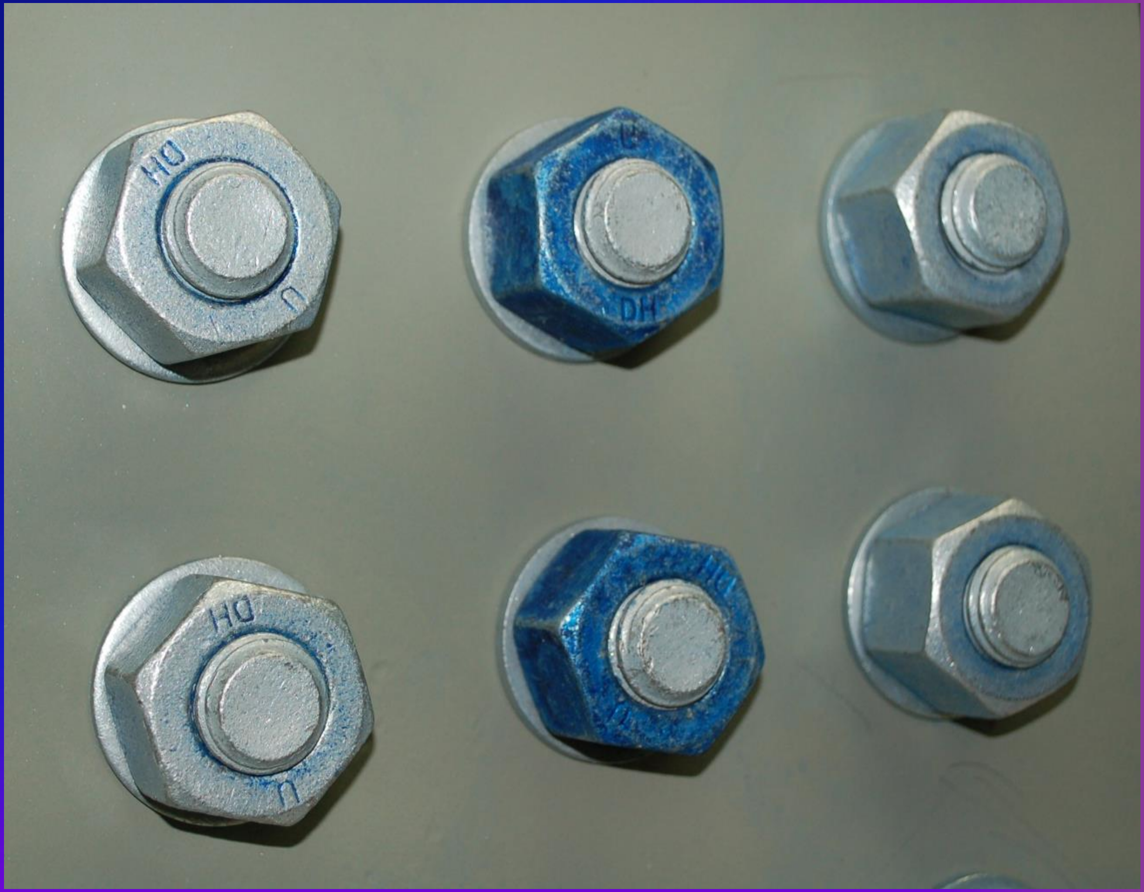
- SSPC-PA Guide 13 recommends that galvanized fasteners be cleaned by solvent cleaning, hand tool cleaning, power tool cleaning, or water jetting
- For lubricant wax/die applied to nuts, it recommends using an alkaline household cleaner such as ammonia.

Cleaning and Painting of Fasteners Galvanized Bolts (con't)

- Section 5.4.4 of the Guide requires the removal of "excessive dye," and in commentary notes to 5.4.4 it states that, "Any dye coloring remaining on galvanized nuts after weathering or the required surface preparation is not believed to be detrimental to subsequent coating performance or appearance. A white cloth wipe test with no color transfer can be used to confirm that all lubricant and nonabsorbed dye has been removed, leaving only the residual 'stain' on the surface."
- Standards are not available that define the amount of residual staining that can be allowed, so it becomes a project-specific decision

Cleaning and Painting of Fasteners Galvanized Bolts (con't)

- Project-specific test
- MEK used to remove the lubricant
- After removal, the residual stain was not removed by rubbing with a white cloth
- Coating adhesion was assessed by knife cutting per ASTM D6677, Standard Test Method for Evaluating Adhesion by Knife
- Adhesion was satisfactory



Cleaning and Painting of Fasteners Galvanized Bolts (con't)

- Damaged galvanizing is usually touched up with either organic zinc primer or epoxy mastic (typically aluminum filled) followed by the same intermediate and finish applied to the rest of the structure
- Difference between "smeared" galvanizing and damaged – smeared is still protective and may not require any touch up

Cleaning and Painting of Fasteners- Paint Application

- No matter what coating is being applied or the degree of cleaning that is used, it is critical that the coating be thoroughly worked into threads and crevices

Summary

- Understand the coefficient of friction and tension creep testing used to certify coatings for slip-critical bolted connections
  - Coefficient of Friction Testing is first, followed by Tension Creep
  - COF testing requires ~7 minutes per test (5 tests total); tension creep testing requires 1,000 hours (42 days)
  - Clamping force for COF is maintained continuously during the test using a hydraulic cylinder; clamping force for tension creep is accomplished using 7/8" A490 bolts
  - Coating must pass the criteria for both tests to be certified
  - Class B is the greatest COF (0.50), Class C (0.35), Class A (0.30)
  - Very tight controls on coating thickness, amount of thinner, dry time
  - Certification is based on a thickness 2.0 mils less than tested

Summary (con't)

- Recognize the challenges associated with using coatings in slip-critical bolted connections
  - Unless specifically tested otherwise, the certification is based on the same coating on the faying surfaces and back side of the plates
  - Unless tested, can not assume that two products that have Class B certifications will meet Class B when mated together
  - Unless tested, there is risk in assuming that coats of paint beneath bolt heads and washer/nuts will not effect bolt pretension (and the tension creep results) – the tests are run with only the primer beneath the bolt and washer/nut
  - Based on an FHWA study, thermal spray coatings exhibit Class B, but are not Class B when sealed
  - The requirements for DFT, thinning, and dry time prior to assembly must be in accordance with the criteria reported in the certification

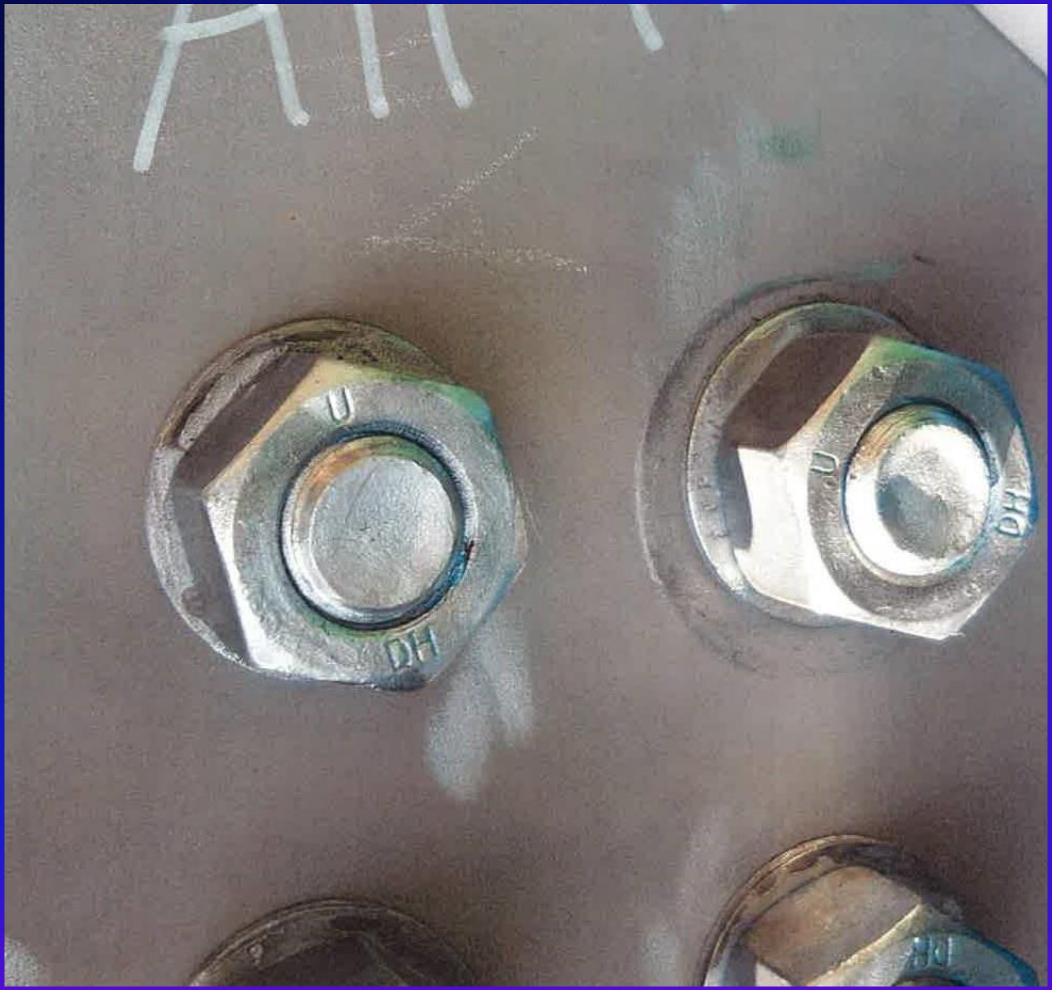
Summary (con't)

- Recognize common approaches for addressing bolt holes (to paint or not to paint)
  - There is no universally accepted approach
  - SSPC PA Guide 13 (which is also AASHTO/NSBA Steel Bridge Collaboration S8.1-2014) indicates that unless specified, paint is not required inside of bolt holes, but overspray is permitted
  - SSPC-PA1, "Shop, Field, and Maintenance Painting of Steel" is under revision - the most recent draft states that the application or removal of coating from bolt hole interiors is not required unless specified, with overspray frequently present

Summary (con't)

- Identify approaches to cleaning and painting galvanized and black fasteners
  - SSPC-PA Guide 13 indicates that black bolts should be blast cleaned, even when installed after the steel has been painted
  - There are significant risks associated with damage to the surrounding coating if the fasteners are blast cleaned
  - Consideration should be given to using treated bolts or galvanized bolts instead of black bolts to eliminate the need for blast cleaning
  - Painting of galvanized fasteners requires the removal of the lubricant/dye from the nuts
  - SSPC-PA Guide 13 states that residual dye that passes a white cloth wipe test after cleaning is not believed to be detrimental
  - The thoroughness of coating application to threads and crevices is critical to the successful performance of the system

Questions?



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