TESTING AND EVALUATION OF IN-PAVEMENT LIGHT FIXTURES

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Background

- **In-Pavement Light Fixture Assemblies Utilize a Circle of Six (6) Bolts and Two Part Locking Washers to Secure Light Fixtures to the Light Bases or Light Base Extensions.**
- **Bolts Used to Secure Light Fixtures to Light Bases or Light Base Extensions are Required to be 3/8 inch diameter, SAE J429 Grade 2 or 18-8 Stainless Steel (ASTM F593C) per FAA AC 150/5345-42 and Engineering Brief (EB) No. 83.**
- **Incidents Have Occurred at Certain Airports Where In-Pavement Light Fixture Bolted Connections Have Failed Resulting in Light Fixtures Completely Separating from the Light Bases or Light Base Extensions. (This triggered a review of the requirements and initiated testing)**

Testing Strategy

- **Project Phase I: Laboratory Testing Conducted by Intertek (FAA Accepted Third Party Certification Body per FAA AC 150/5345-53).**
  - **Developed Torque-Tension Relationships for Bolts Required in FAA EB 83 and Bolts Having Greater Strengths.**
  - **Determined Strength Limitations of Light Fixture Assemblies for Resisting Bolt Clamping Forces Generated Up to Failure of Bolts.**
  - **Conducted Shear Force, Compressive Load, and Vibration Testing to Evaluate Performance of Light Fixture Assemblies Based on Bolt Clamping Forces Generated (75% of Bolt Material Proof Load or Yield Strength).**
  - **Conducted Corrosion Tests with All Bolt Grades and Coatings.**
- **Project Phase II: Field Testing to be Conducted in National Airport Pavement Test Facility (NAPTF).**
  - **Instrument and Install In-Pavement Light Fixtures in the NAPTF.**
  - **Conduct Testing with NAPTF Test Vehicle Generating Controlled Aircraft Wheel Loading Conditions.**

Diameters and Mechanical Properties of Bolts Included in Testing

Diameter (in)	Bolt Type	Yield Strength (lbs)	Proof Strength (lbs)	Tensile Strength (psi)	Stress Areas (in^2)	Yield Load (lbs)	Proof Load (lbs)	75% of Proof or Yield (lbs)	Ultimate Load (lbs)
3/8"	SAE J429 Grade 2 CS (Coated)	NA	55,000	74,000	0.0775	NA	4263	3197	5735
3/8"	SAE J429 Grade 5 CS (Coated)	NA	85,000	120,000	0.0775	NA	6588	4941	9300
3/8"	ASTM F593C Grade 304 SS	65,000	NA	100,000	0.0775	5038	NA	3778	7750
				150,000					11625
3/8"	ASTM F593P 410 SS-black oxide	90,000	NA	110,000	0.0775	6975	NA	5231	8525
				140,000					10850
7/16"	SAE J429 Grade 5 CS (Coated)	NA	85,000	120,000	0.1063	NA	9036	6777	12756
7/16"	ASTM F593P 410 SS-black oxide	90,000	NA	110,000	0.1063	9567	NA	7175	11693
				140,000					14882

Project Phase I – Intertek Testing

Torque-Tension Relationships

- **Torque-Tension Relationships Were Developed for All Combinations of Bolts, Light Fixtures, Light Base Extensions, and Two Part Locking Washers. Stainless Steel Bolts were Lubricated with a Marine Grade Anti-Seize. Carbon Steel Bolts were Supplied with Coatings Providing both Lubricating Characteristics and Corrosion Resistance.**
- **Average Friction Coefficients (K's) were Calculated Based on Measurements Recorded from Calibrated Torques Wrench and Skidmore-Wilhelm Bolt Tension Calibrator.**
- **Average Friction Coefficients Calculated for SAE J429 Grade 2 Coated Bolts were Significantly Greater Than Range Identified in EB-83.**

Torque-Tension Relationships

Bolt	75% of proof or yield (lbs)	Light Fixture	Light Base Extension	Average K	Torque (inlbs)
3/8" SAE J429 Grade 5 (Red)	4941	LSA	IA	0.160	296.5
3/8" SAE J429 Grade 5 (Red)	4941	DIR	IA	0.166	307.6
3/8" SAE J429 Grade 5 (Red)	4941	LSA	IB	0.158	292.8
3/8" SAE J429 Grade 5 (Red)	4941	DIR	IB	0.162	300.2
3/8" SAE J429 Grade 2	3197	LSA	IA	0.198	237.4
3/8" SAE J429 Grade 2	3197	LSA	IB	0.199	238.6
3/8" SAE J429 Grade 2	3197	DIR	IB	0.197	236.2
3/8" SAE J429 Grade 2	3197	DIR	IA	0.216	259.0
3/8" F593P-black oxide(anti-seize)	5231	LSA	IA	0.212	415.9
3/8" F593P-black oxide(anti-seize)	5231	LSA	IB	0.215	421.7
3/8" F593P-black oxide(anti-seize)	5231	DIR	IA	0.198	388.4
3/8" F593P-black oxide(anti-seize)	5231	DIR	IB	0.215	421.7
3/8" F593C (anti-seize)	3778	DIR	IB	0.157	222.4
3/8" F593C (anti-seize)	3778	DIR	IA	0.172	243.7
3/8" F593C (anti-seize)	3778	LSA	IA	0.155	219.6
3/8" F593C (anti-seize)	3778	LSA	IB	0.153	216.8

Torque-Tension Relationships

Bolt	75% of proof or yield (lbs)	Light Fixture	Light Base Extension	Average K	Torque (inlbs)
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IA	0.152	451.2
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IB	0.157	466.0
7/16" SAE J429 Grade 5 (Red)	6777	LSA	IA (GARDSERT)	0.178	528.4
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IA (GARDSERT)	0.166	492.7
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IA	0.159	472.0
7/16" SAE J429 Grade 5 (Red)	6777	DIR	IB	0.176	522.4
7/16" F593P-black oxide(anti-seize)	7175	LSA	IA	0.239	751.1
7/16" F593P-black oxide(anti-seize)	7175	LSA	IB	0.257	807.7
7/16" F593P-black oxide(anti-seize)	7175	DIR	IA	0.208	653.7
7/16" F593P-black oxide(anti-seize)	7175	DIR	IB	0.251	788.8
7/16" F593P-black oxide(anti-seize)	7175	LSA	IA(GARDSERT)	0.252	791.9
7/16" F593P-black oxide(anti-seize)	7175	DIR	IA(GARDSERT)	0.255	801.4

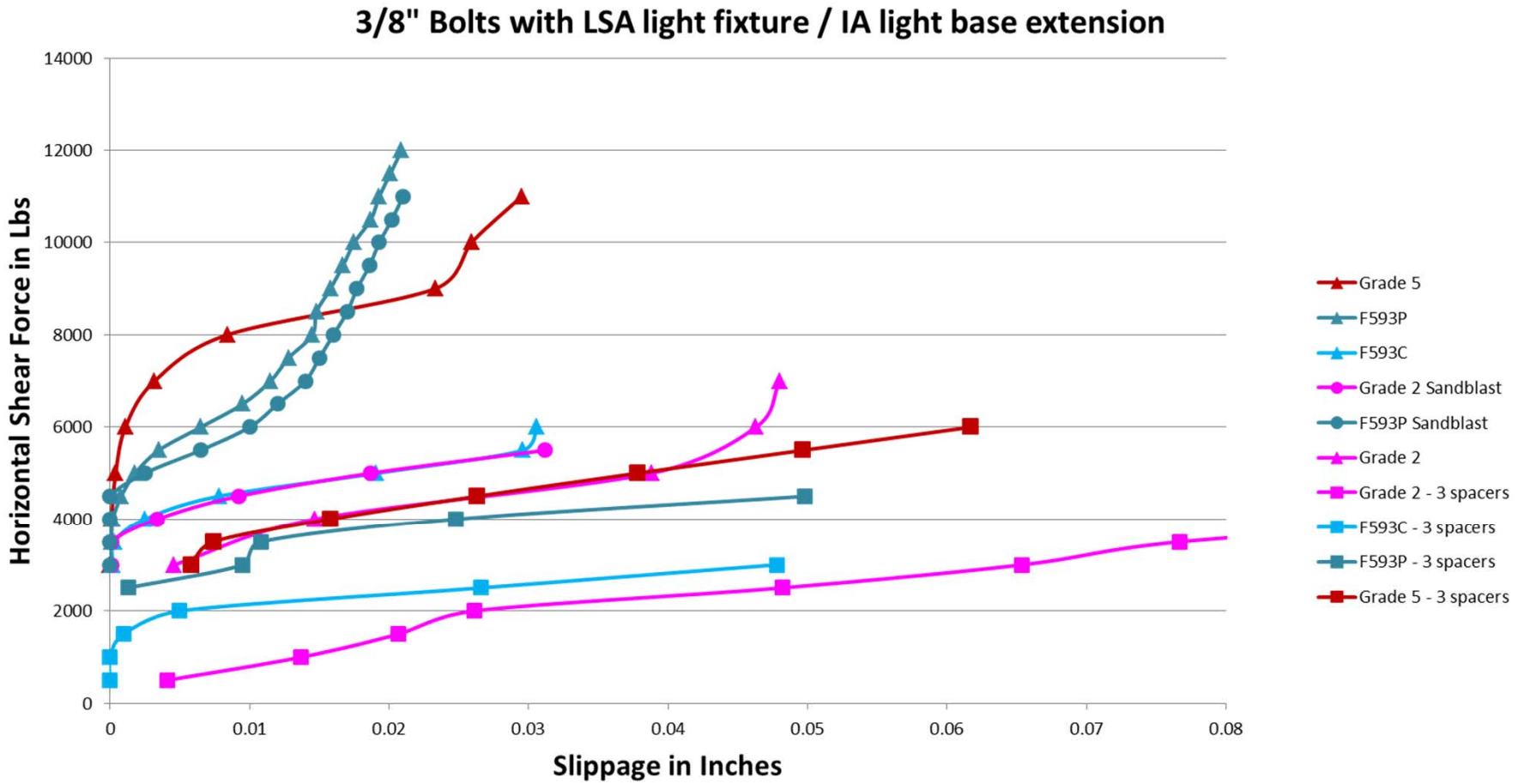
Horizontal Shear Force Testing

- **Testing Conducted on All Combinations of Light Fixture Assemblies to Record Forces at which Joint Slippage Occurred.**
- **Slip Coefficients Calculated Based on Shear Forces Recorded at 0.020” Joint Slippage.**
- **Testing Included Assemblies with No Spacers, One 1/16” Spacer Ring, and Three Spacer Rings (1/16”+1/2”+1”).**
- **Testing Included Evaluation of Methods for Increasing Friction at Faying Surfaces (Sandblasting of Galvanized Steel Mounting Flange and Removal of Coating from Ductile Iron Adaptor Ring).**

Horizontal Shear Force Testing (Continued)

- **Testing Conducted with Application of Horizontal Shear Forces (A380-800 Aircraft Maximum Normal/Traction Wheel Loads) Based on Static Friction Coefficients Derived from Testing, Utilizing 7/16 Inch Diameter Bolts.**
- **Testing Conducted with Application of Horizontal Shear Forces (A380-800 Aircraft Maximum Normal/Traction Wheel Loads) Based on Static Friction Coefficients Derived from Testing with Reduced Clearances Between Light Fixture Projections and Light Base Flange Inside Diameters.**
- **Slip Coefficients Calculated with No Spacer Rings were Significantly Lower Than Static Friction Coefficient of 0.45 used in FAA EB 83.**
- **Testing with Spacer Rings, Not Addressed in FAA EB 83, Resulted in Even Lower Slip Coefficients.**

Horizontal Shear Force Plots



Summary of Findings

- **Skidmore-Wilhelm Bolt Tension Calibrator and Calibrated Torque Wrench were Effective in Relating Target Clamping Forces with Installation Torques.**
- **Static Friction Coefficients, Used to Calculate Required Bolt Clamping Forces, Varied Significantly Based on Particular Faying Surface Conditions and the number of Spacer Rings installed.**
- **Light Fixtures and Bases were able to Safely Absorb the Clamping Forces Developed by All Bolts Tested.**
- **Spacer Rings Increased Number of Faying Surfaces Resulting in Significantly Reduced Overall Static Friction Coefficients.**

Summary of Findings (Continued)

- **Sandblasting of Faying Surfaces can Increase Static Friction Coefficients.**
- **Horizontal Shear Forces Can be Effectively Transmitted Through Light Fixture Projections to Light Base Flange Bore Interfaces By Reducing Diametral Clearances.**
- **Torqueing of Stainless Steel Bolts with Marine Grade Anti-Seize Applied, Generated a Stable Average Friction Coefficient Consistent with Manufacturer's Published K Value.**
- **Light Fixtures and Bases Were Able to Accommodate Larger 7/16" Diameter Bolts with Associated Increased Clamping Forces.**

Project Phase II – Testing in NAPTF

Planned Testing in NAPTF

- **Six Instrumented Light Fixture Assemblies will be Installed in an Asphalt Pavement Test Section.**
- **Light Fixture Assemblies will be Installed at Varying Elevations to Evaluate Influence of Varying Spacer Ring Stack Heights on Light Fixture Assembly Performance.**
- **Instrumentation on Light Fixture Assemblies will Include the following:**
  - **Strain Gauges Installed on Light Fixtures, Bases, and Bolts**
  - **Tri-Axial Accelerometers Installed on Light Fixtures**
  - **Laser Transducers to Measure Horizontal and Vertical Movement Between Light Fixtures and Bases**

The National Airport Pavement Test Vehicle

Planned Testing in NAPTF (Continued)

- **NAPTF Test Vehicle will be used for Trafficking in the Asphalt Test Section, Applying Incrementally Increasing Wheel Loads at Varying Distances from the Light Fixture Assemblies.**
- **Construction of Asphalt Pavement Section, Installation of Instrumented Light Fixture Assemblies, and Testing Scheduled to Begin in Spring 2018.**

General Direction

- **Light Fixture to Base Connections Considered to be Slip Critical Based on Potential for Shear Force Reversal Conditions.**
- **Light Fixture Mounting Bolts Selected to Develop Clamping Forces Necessary to Resist Governing Aircraft Wheel Loading (A380-800) Based on Applicable Static Friction Coefficients.**
- **Bolt Installation Torque shall be able to Develop a Clamping Force of 4,900 lbs. to Resist Governing Aircraft Wheel Loading.**
- **Bolt Installation Torques Determined Utilizing Skidmore-Wilhelm Bolt Tension Calibrators and Calibrated Torque Wrenches to Ensure Accuracy of Bolt Clamping Forces for Particular Installations.**
- **Minimize the Quantity and Overall Height of Spacer Ring Stacks.**

General Direction (Continued)

- **Faying Surfaces to be Sand Blasted or Possibly Provided with Coatings to Increase Static Friction Coefficients. Possible Requirement to establish Static Friction Coefficients for In-Pavement Light to Base Faying Surfaces.**
- **Working with Light Fixture and Base Manufacturer's, Assess Feasibility of Effectively Transmitting Horizontal Shear Forces Through Light Fixture Projections to Light Base Flange Bore Interfaces By Reducing Diametral Clearances. Presence of Spacer Rings Needs to be Considered.**
- **Working with Light Fixture and Base Manufacturer's, Assess Feasibility of Increasing the Size and/or Quantity of Bolts in Connections.**
- **Reduce Potential for Light Fixture to Base Horizontal Movement by Reducing Clearances Between Light Fixture Holes and Bolts, and Either Welding Spacer Rings or Threading Spacer Ring Holes.**

Short Term Changes Via EB 83

- **Bolts Shall be Capable of Generating a Minimum Clamping Force of 4,900 lbs. While Not Exceeding 75% of Bolt Material Proof Load or Yield Strength.**
- **Minimum Clamping Force Based on Resisting A380-800 Aircraft Maximum Normal/Traction Wheel Loads based on an Assumed Static Friction Coefficient of 0.40.**
- **Minimum Clamping Force Requirement will Require use of Bolts with Strengths Equal to or Greater Than SAE J429 Grade 5 Coated Bolts or ASTM F593P Bolts.**
- **The Bolting System Shall be Tested Utilizing a Skidmore-Wilhelm Bolt Tension Calibrator and Calibrated Torque Wrench to Establish the Required Bolt Installation Torque.**
- **Testing with Skidmore-Wilhelm Bolt Tension Calibrator will Account for Bolt Lubricant or Coating, and Mechanical Properties of Materials in Grip (Light Fixtures, Bases, Two Part Locking Washers, and Bolts).**

Short Term Changes Via EB 83 (Continued)

- **Coatings shall be applied to carbon steel bolts and shall be selected for both corrosion resistance and lubricating properties. The bolt manufacturers must determine whether coating thicknesses will require under-sizing of bolt threads to ensure proper mating with internal threaded holes in base flanges.**
- **Stainless Steel Bolts shall be Installed with a Marine Grade Lubricant Which Generates Stable Installation Torques Consistent with Lubricant Manufacturer's Published K Value.**
- **All faying surfaces (i.e. light fixture bases, base flanges, and spacer rings) shall be sand blasted or possibly having coatings applied to develop necessary static friction coefficient.**
- **Minimize the Use of Spacer Rings. Limit of Two Spacer Rings, not to exceed 2 ¼" Stack Height. If Installation Requires a Stack Height Exceeding 2 ¼", an Extension Can Shall Be Used.**
- **Requirement for Two Part Locking Washers or Equivalent "Locking" Mechanisms.**
- **Changes to Applicable FAA Advisory Circulars to Reflect Changes in EB 83.**
- **Recommend "Torque" Verification after/during Winter Operations to Consider Impact of Snow Plow Operations.**

Long Term Changes

- **Develop Testing Requirements to Accurately Determine Static Friction Coefficients developed in individual Light Fixture to Base Faying Surfaces.**
- **If Feasible, Incorporate Criteria Requiring Light Fixture Projection to Light Base Flange Bore Interfaces (with Reduced Diametral Clearances) be Capable of Transmitting Horizontal Shear Forces Independent of Bolted Connections.**
- **If Feasible, Increase the Size and/or Quantity of Bolts in Connections.**
- **Require Reduction in Diametral Clearances Between Light Fixture Holes and Bolts, and Either Welding Spacer Rings or Threading Spacer Ring Holes.**
- **Better organize the ACs. Have all hardware and maintenance in – 42.**
- **Consideration for generic requirements for maintenance issues.**

Questions?